PB82-259151

Airport Noise
Land-Use Compatibility by the Year 2000

(U.S.) Environmental Protection Agency
Washington, DC

Aug 82

U.S. Department of Commerce
National Technical Information Service
NTIS

PB82-259151

United States
Environmental Protection
Agency

EPA 550/9-82-344

AIRPORT NOISE

LAND-USE COMPATIBILITY BY THE YEAR 2000

AUGUST 1982

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF NOISE ABATEMENT AND CONTROL
WASHINGTON D.C. 20460

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. EPA 550/9-82-344	2.	3. Recipient's Accession No. PB82 259151

4. Title and Subtitle
AIRPORT NOISE: LAND-USE COMPATIBILITY BY THE YEAR 2000

5. Report Date AUGUST 1982

6.

7. Author(s)
ROBERT J. KOENIG AND JOHN TYLER

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Same as box 12.

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF NOISE ABATEMENT & CONTROL
AIRPORT & CONSUMER AFFAIRS BRANCH - ANR-471C
WASHINGTON D.C. 20460

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report reviews the progress which has been made in airport noise control and presents a forecast of changes in aviation noise exposure that will occur during the balance of this century. Results are given of an analysis which examines the benefits of noise abatement flight operations, flight procedures and of restrictions on population encroachment, on residential noise exposure. Cost of residential soundproofing and relocation, based upon in-depth studies, are presented for four air carrier airports which represent four airport categories. While the main focus of the report is on noise exposure above Ldn 65 at air carrier airports, noise exposure around general aviation and joint-use civil/military airports is also discussed.

17. Document Analysis a. Descriptors
NOISE CONTROL
AIRPORT NOISE
LAND-USE PLANNING - AIRPORT NOISE

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement: UNLIMITED	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages
	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

AIRPORT NOISE -- LAND USE COMPATIBILITY BY YEAR 2000

TABLE OF CONTENTS

CHAPTER		PAGE
	SUMMARY	ii
	INTRODUCTION	iv
1	AVIATION-NOISE-EXPOSURE GOALS	1-1
2	FEDERAL POLICY AND CASE LAW	2-1
3	ACTIONS TO DATE	3-1
4	PROSPECTS FOR THE FUTURE	4-1
5	DEVELOPMENT OF NOISE-EXPOSURE ESTIMATES	5-1
6	NOISE-EXPOSURE-REDUCTION AND COMPATIBILITY COSTS	6-1
7	GENERAL AVIATION AND JOINT CIVIL/MILITARY AIRPORTS	7-1
	APPENDIX A	A-1
	APPENDIX B	B-1
	REFERENCES	R-1

SUMMARY

This report presents the status of residential exposure to aviation noise and a forecast of changes in aircraft-noise exposure that will occur during the balance of this century, and it identifies the residual areas that require land use change to achieve airport noise/land use compatibility by the year 2000.

The national goal for aviation noise is to confine noise exposure above L_{dn} 65 dB* to the airport boundaries and to those areas that are used for purposes that are compatible with their exposure to noise (not residential). The Environmental Protection Agency (EPA), the Federal Aviation Administration (FAA), the Department of Defense (DOD), and the Department of Housing and Urban Development (HUD) all have similar noise-exposure goals for aviation.

The number of people exposed to above L_{dn} 65 dB* will shrink significantly during the 1980's with the replacement of the noisiest aircraft in the air carrier fleet with quieter aircraft. During the 1990's, there will be additional reduction in aircraft-noise levels with the increased use of the newest technology aircraft, which are now being produced. Therefore, the residential exposure will probably be minimal about the year 2000. Those calculations are based on information in "FAA Aviation Forecasts, Fiscal Years 1981 - 1992," which concerns airport operations and types of aircraft that will be in the air carrier fleet through 1992, and a continued moderate growth for operations and fleet replacements through 2000.

This report also contains an analysis of the effect of noise abatement flight procedures and airport operations. Although those procedures will appreciably affect the exposed residential areas, there will still be residual areas in the year 2000 where land use change will be needed to achieve compatibility.

---

*The outdoor annual average day/night sound level.

The FAA points out in its report to Congress, "Airport Noise Compatibility Planning and Programs, October 1981," that 85-90 percent of the airport-noise impacted area is already developed as residential property, which makes zoning to prevent residential development near airports ineffective. The FAA also points out, in its advisory circular, "Airport-Land Use Compatibility Planning, AC 150/5050-6, December 30, 1977," that soundproofing houses is a relatively inexpensive way to provide a compatible noise environment (inside the houses). To determine how costly the soundproofing strategy would be if the noise-impacted areas were first reduced to a minimum by reductions in aircraft noise and by flight and airport noise-abatement procedures, the EPA has conducted an analysis of soundproofing costs at four representative airports for 1979, 1990, and 2000. The cost of relocating some families from critically high exposure areas was also considered. While soundproofing houses does not provide the same relief as reduction of airport noise to L_{dn} 65 dB, it is the most practical step toward compatibility currently available.

As outlined by the Department of Transportation in its aviation-noise-abatement policy, November 1976, the decisions and conditions regarding land use change and noise-abatement programs and their funding must be worked out by negotiation between the airport operator and the communities impacted by airport noise. The EPA has therefore developed procedures for determining soundproofing and relocation costs at airports and presents data for the four representative airports in this report. Those procedures involve a determination of the changes in areas and people impacted for a reference case and determinations of the benefits in terms of reductions in areas and people impacted as a result of the following:

1. the use of noise-abatement flight procedures,
2. the use of priority runways and curved flight tracks, and
3. restrictions on population encroachment into aircraft-noise-impacted areas.

While the main focus of the report is on noise exposure above L_{dn} 65 dB at air carrier airports, noise exposure around general aviation airports and joint-use civil/military airports is also discussed.

INTRODUCTION

Progress has been made in reducing the aviation-noise problem. The Federal Aviation Administration (FAA) in coordination with the Environmental Protection Agency (EPA) has promulgated a number of important regulations that, when fully effective, will provide significant relief for many people around our nation's airports who are now exposed to high levels of noise from aircraft operations.

Progress has also been made at the local level. Both the courts and the Federal Government have articulated more clearly the rights and responsibilities of airport proprietors to reduce the noise levels from their facilities. Federal legislation has been initiated to assist in the development of plans that lay the groundwork for and in some cases the financing of the implementation of such plans.

Despite that progress, many aviation-noise problems remain. There is still widespread dissatisfaction among those who live in the vicinity of airports with the current level of aircraft-noise-abatement progress. Community objection to aircraft noise has in some cases already resulted in airport restrictions such as imposition of night curfews, prohibition of specific types of aircraft, and limitations on expansion of existing airports. Construction of new airports is also being opposed. Legal action involving noise-damage claims is continuing.

This report has been prepared by the EPA in accordance with its broad mandate to implement and coordinate the Federal Government's overall efforts to control noise. Many significant actions have been taken to alleviate the aircraft/airport-noise problem since the "1973 Report to Congress on Aircraft-Airport Noise."[1] This report reviews the progress that has been made in reducing the aviation-noise problem and summarizes recent EPA studies of methods of achieving compatibility between airports and adjacent communities by the year 2000. It can be used by state and local governments and airport operators as a guide to define solutions for site-specific airport noise/land use-compatibility problems.

This report measures the results of aviation-noise-abatement actions taken to date against the common FAA and EPA goals for aviation-noise-exposure reduction. While considerable progress has been made, EPA studies show that the noise-exposure goals will not be reached unless further action is taken at all levels of concern.

This report contains seven chapters.

Chapter 1 identifies national aviation-noise-abatement goals.

Chapter 2 reviews the Department of Transportation aviation noise abatement policy and an EPA review of airport noise litigation, to provide a background for understanding and use of the content of this report.

Chapter 3 describes actions taken at the Federal, state, and local levels to control aviation noise.

Chapter 4 identifies methods and procedures where further progress can be made toward achieving airport-noise/land use compatibility.

Chapter 5 covers the development of a noise exposure data base, which provides a basis for the noise-exposure-reduction analysis presented in Chapter 6. It also provides estimates of the number of people who are presently exposed to above L_{dn} 65 dB and of those who will continue to be exposed to those levels in 2000.

Chapter 6 presents the results of a noise exposure-reduction analysis by applying the noise control measures covered in Chapter 4 to four airports and provides estimates of the cost of land use compatibility at those airports by the year 2000. The purpose of Chapter 6 is to illustrate the application of noise-exposure-reduction procedures and land use-compatibility costs to specific airport cases.

Chapter 7 gives results of EPA studies of noise exposure for the year 2000 for general aviation airports and for airports where both civil and military operations are conducted. National conferences on general aviation noise and land use planning held in 1979 and 1981 are discussed.

Appendices A and B provide summaries of a study of soundproofing requirements for residences adjacent to commercial airports and of a study of procedures to estimate residential relocation costs.

CHAPTER 1. AVIATION-NOISE-EXPOSURE GOALS

Three Federal agencies have responsibilities for establishing Federal policy for civil aviation-noise control and abatement. The Federal Aviation Administration (FAA) has the primary responsibility through its authority to regulate aircraft noise emissions and flight procedures. The Environmental Protection Agency (EPA) and the Department of Housing and Urban Development (HUD) exercise mandates that cut across many sources of noise, including aviation noise.

EPA has the responsibility to coordinate all Federal noise activities and policies. In addition, in the aviation noise area, EPA is required to make specific recommendations to the FAA regarding aviation-noise regulations that are necessary to protect the public health and welfare.

HUD establishes guidelines for the use of Federal housing and redevelopment assistance in areas impacted by noise, including aviation noise. Those guidelines presently represent the Federal policy on identification of land uses that are compatible with high noise exposures.

In keeping with its mandate to coordinate Federal efforts to control noise, EPA, in 1977, established some tentative goals for noise from all sources in its publication "Toward a National Strategy for Noise Control."[2] Three of these noise-exposure goals for the nation are given in terms of annual average outdoor day/night levels of community exposure, L_{dn}, expressed in decibels as follows:

1. "Reduce environmental noise exposure of the population to an L_{dn} value of no more than 75 dB immediately, using all available tools, except in those isolated cases where this would impose severe hardship."
2. "Through vigorous regulatory and planning actions, reduce environmental noise exposure levels to L_{dn} 65 dB or lower, and concurrently reduce noise annoyance and related activity interference caused by intrusive noises."

3. "In planning future programs concerned with or affecting environmental noise exposure, to the extent possible, aim for environmental noise levels that do not exceed an L_{dn} 55 dB. This will ensure protection of the public health and welfare from the adverse effects of noise based upon present knowledge."

In its policy document,[3] the FAA has specified noise-abatement goals that deal with the noise in areas near air carrier airports as follows:

> "The objective of airport noise plans prepared under this policy should be to develop noise reduction techniques which, to the maximum extent feasible, confine severe aircraft noise exposure levels, levels of 40 NEF (75 L_{dn}) or more, to areas included within the airport's boundary. For areas adjacent to an airport exposed to significant airport noise levels of 30 NEF (65 L_{dn}) or more, the objective of the airport noise plan should be to develop noise reduction techniques that to the extent possible would confine the area exposed to this level of noise to the airport boundary or land actually being used or which can reasonably be expected to be used in a way compatible with these noise levels.

As pointed out above, the FAA's goal is to confine noise exposure at and above 30 NEF (L_{dn} 65 dB) to the airport boundaries or to those land areas that are used for purposes that are compatible with their exposure to noise (not residential). The FAA goals are compatible with EPA goals and with the HUD land use guidelines[4] as well as with state aviation-noise regulations in California and Maryland. Consequently, those goals form the basis for evaluation of progress to date and for the future discussed in this report.

CHAPTER 2. FEDERAL POLICY AND CASE LAW

INTRODUCTION

Congress and the courts have delegated specific responsibilities in some areas and have placed specific restrictions in other areas on the various parties involved in the control of aircraft-noise impact. To provide a background for the following chapters of this report, a review of Federal aviation-noise policy and airport-noise litigation is presented in this chapter. Federal policy is covered chiefly by direct quotation from the Department of Transportation, "Aviation Noise Abatement Policy,"[3] issued in November 1976 and currently under revision. A study conducted for the EPA, published in April 1981,[5] covered an airport-noise litigation case law review. Direct quotations are cited frequently from this study in the review of case law presented below.

AVIATION-NOISE-ABATEMENT-POLICY

The following quote from the Department of Transportation (DOT) policy document indicates the motivation for passage of Federal aircraft-noise-control legislation:

> "Because of the increasing public concern about aircraft noise that accompanied the introduction of turbojet powered aircraft into commercial service in the 1960s and the constraints such concern posed for the continuing development of civil aeronautics and the air transportation system of the United States, the federal government in 1968 sought - and Congress granted -- broad authority to regulate aircraft for the purposes of noise abatement."

The policy document covers significant amendments to the statute.

> "In 1972, the Congress amended that statute in two important respects. To the original statement of purpose 'to afford present and future relief from aircraft noise and sonic boom' --it added consideration of 'protection to the public health and welfare.'"

Also,

> "While the federal government's exclusive statutory responsibility for noise abatement through regulation of flight operations and aircraft design is broad, the noise abatement responsibilities of state and local governments through exercise of their basic police powers are circumscribed."

But

> "There remains a critical role for local authorities in protecting their citizens from unwanted aircraft noise, principally through their powers of land use control."

The document then shows that the courts have placed on the airport proprietor the legal responsibility for noise impact on the community and the power to control that impact. But it cautions

> "The power thus left to the proprietor - to control what types of aircraft use its airports, to impose curfews or other use restrictions, and, subject to FAA approval, to regulate runway use and flight paths, is not unlimited. Though not preempted, the proprietor is subject to two important Constitutional restrictions. He first may not take any action that imposes an undue burden on interstate or foreign commerce and, second may not unjustly discriminate between different categories of airport users."

The conclusion reached in the policy document with regard to legal responsibilities is stated as follows:

> "Our concept of the legal framework underlying this policy statement is that proprietors retain the flexibility to impose such restrictions if they do not violate any Constitutional proscription. We have been urged to undertake - and have considered carefully and rejected - full and complete federal preemption of the field of aviation noise abatement. In our judgment the control and reduction of airport noise must remain a shared responsibility among airport proprietors, users, and governments."

The legal framework with respect to noise is summarized in the document as follows:

1. "The federal government has preempted the areas of airspace use and management, air traffic control, safety and the regulation of aircraft noise at its source. The federal government also has substantial power to influence airport development through its administration of the Airport and Airway Development Program."
2. "Other powers and authorities to control airport noise rest with the airport proprietor including the power to select an airport site, acquire land, assure compatible land use, and control airport design, scheduling and operations - subject only to Constitutional prohibitions against creation of an undue burden on interstate and foreign commerce, unjust discrimination, and interference with exclusive federal regulatory responsibilities over safety and airspace management."
3. "State and local governments may protect their citizens through land use controls and other police power measures not affecting aircraft operations. In addition, to the extent they are airport proprietors, they have the powers described in paragraph 2."

REVIEW OF AIRPORT NOISE LITIGATION

The review of aircraft-noise legislation conducted for the EPA[5] provides some historical perspective on the judicial trends in airport-noise litigation by examining many of the relevant cases that have been scrutinized in the courtroom. Selected quotations are given below that are considered particularly significant:

1. "This extensive review of the most relevant judicial decisions on aircraft noise litigation indicates that the courts continue to hold the airport proprietor liable for damages resulting from aircraft noise. At the same time, the judiciary is broadening the legal theories associated with noise litigation and is granting recovery for noise related effects on people under the nuisance theory for emotional distress as well as under the traditional

inverse condemnation theory for deprivation of property. As a result of this increase in potential liability, the airport proprietors and the municipality nonproprietors,* with or without federal guidance, are implementing airport use restrictions in an attempt to decrease objectionable noise levels and avoid a possible lawsuit. Because of the lack of definitive federal direction in these regulatory matters, the courts have been forced into the position of the rulemaker to determine on a case by case basis, how close the use restrictions come to encroaching upon an area historically perceived to be federally preempted."

2. "Court history from Griggs,[6] 1962 (supra) to Greater Westchester,[7] 1980 (supra) has consistently placed liability for aircraft noise effects experienced by property owners squarely upon the airport proprietor. The federal government (unless acting as an airport proprietor) has been absolved from financial responsibility for airport related noise problems."

With regard to airport proprietor's authority, the review states the following:

> "As evidenced by the analysis of the previous cases, the courts have carefully guarded the airport proprietor's authority to control airport operations. They have approved legislative or judicially imposed restrictions on a very limited basis and only in cases where there is no interference in a federally preempted area. The courts and the federal government will, in all probability, continue this trend in support of airport proprietor generated regulations. If non-airport proprietors were allowed to enact regulations which restrict airport operations, it might well invite a decline in economic growth for the airport and the communities that are served by them. On the other hand, the rules adopted by the airport proprietors appear to be tempered by the economic

---

*Municipality nonproprietors have influenced ground operations where FAA preemption does not apply.

> interest of maintaining a viable and profitable airport enterprise. More importantly, if the airport proprietors are to be held liable for noise-related damages, then they should have the regulatory means to promulgate noise abatement measures and hopefully decrease the chances of additional aircraft noise inspired litigation."

Under the heading "Legal Theories and Trends in Awarding Damages," the review states

> "When people are subjected on a daily basis in their homes to the sound of aircraft takeoffs and landings, they want relief from the noise. That is, ideally they would like the court to issue an injunction and have the aircraft operations cease and desist. However, this is not a practical solution to such a complex problem, and instead the annoyed community seeks relief that is usually spelled (as the cases will attest): MONEY"

The review then discusses the court's decisions in this area through 1980. In the case of Greater Westchester Homeowners Association v. City of Los Angeles, the judge

> "....based on his findings of emotional distress not upon any physical injury (such as hearing loss), but rather based the amount of recovery upon personal testimony evidence to establish the intensity of effects and duration of aircraft noise exposure. The ruling also included the admonition that the compensation for these past injuries would not prohibit these very same plaintiffs from bringing the same cause of action for subsequent injuries from the continuing aircraft nuisance. This rather liberal interpretation of personal injury nuisance law as it relates to aircraft noise was a clear warning to the airport operators to take a more affirmative position in seeking aircraft noise abatement solutions."

The review explains the plight of the airport proprietor as follows:

> "While the airport operator has an economic incentive to abate the noise levels, the necessary authority to achieve this goal is limited by the federal plenary powers in inter-

state commerce and navigable airspace. The DOT 'Aviation Noise Abatement Policy,' published by the FAA/Department of Transportation in 1976, stated that the FAA would 'review and advise' the airport operator as to the acceptability of any operational use restrictions that the airport proprietors might want to impose. However, the FAA declined an invitation to 'review and advise,' the San Diego Port District in a dispute with the State of California over whether to extend a curfew (Gianturco, supra)."

CHAPTER 3. ACTIONS TO DATE

INTRODUCTION

Progress has been made in the control of aviation noise since the EPA reported to the Congress on that subject in 1973.[1] Progress made since 1973 is described in this chapter in terms of Federal, state, and local actions. As will be seen, the roles of each of those levels of government have been significantly clarified during the last nine years, although the boundaries between the authorities of the three levels are still not entirely clear.

The Federal Aviation Administration (FAA) regulates the manufacturers of aircraft and, to a lesser extent, the air carriers regarding the design, production, and use of quieter aircraft in the U.S. fleet. The National Aeronautics and Space Administration (NASA) carries out research on the design of quieter aircraft, and both the FAA and NASA study and demonstrate noise-abatement flight procedures to promote the development and incorporation of new techniques by aircraft manufacturers and operators. The FAA also controls airspace use and management, air traffic control, and safety, all of which can affect noise around an airport.

State and local governments, acting as proprietors of airports, control the selection of airport sites and the acquisition of buffer zones around airports; they also control airport design, scheduling, and operations -- subject to the Constitutional prohibitions against creation of an undue burden on interstate and foreign commerce, unjust discrimination, and interference with exclusive Federal regulatory responsibilities over safety and airspace management.

All states and local communities, regardless of whether they are airport proprietors, may protect their citizens through land use controls and other police powers, provided they do not transgress areas of Federal regulation or the airport proprietor's rights.

FEDERAL ACTIONS

The Federal Government has been very active during the past nine years in controlling aviation noise. Activities fall into four basic categories, ensuring that

1. through regulations and research, quieter aircraft are designed, produced, and operated in the U.S. fleet;
2. consideration is given to employing noise-abatement flight procedures;
3. consideration is given to optimizing aircraft flight ground tracks into and out of airports; and
4. airport proprietors and local officials are assisted in carrying out noise-abatement actions.

Source Regulation and Research

The "EPA 1973 Report to Congress" highlighted the essential need to control the amount of noise generated by aircraft if the overall noise from the U.S. fleet of commercial aircraft was to be significantly reduced. As a general rule, control of noise at the source (the aircraft) is more cost effective than trying to protect people from an excessively noisy source at each location where the aircraft operates.

In 1969, the FAA took the first major step in that direction by issuing a new Federal Aviation Regulation Part 36 (FAR 36),[8] requiring that new-design aircraft be certificated to meet specified noise levels. Those 1969 noise standards came to be known as Stage 2 levels. The unregulated aircraft in operation before 1969 were designated Stage 1 aircraft.

Although FAR 36 was an excellent first step in aircraft noise regulation, it was understood by both the FAA and the industry that many other problems needed to be resolved. The 1969 rule applied only to new-design aircraft, which left the manufacture of older-design aircraft unregulated. Thus, in 1973, more than 90 percent of the approximately 2,000 U.S. jet-powered carriers were older-design aircraft, which did not meet the Stage 2 noise levels. Furthermore, due to the long structural and economic life of these aircraft, they would probably remain in the fleet for 10 to 20 years or more as a significant factor in the airport-noise problem.

In 1973, the FAA issued a rule[9] that required that older-design air carrier aircraft manufactured after December 31, 1974 comply with the Stage 2 noise levels. That rule subjected the manufacturer of all turbojet subsonic air carrier aircraft to the Stage 2 limits. In addition, in December 1976, the FAA set a phased compliance schedule[10] by which large turbojet aircraft in the U.S. fleet not engaged in foreign commerce were to be brought into compliance with Stage 2 noise levels, regardless of when they were designed or manufactured. Compliance with the December 1976 rule can be achieved by the acoustic modification (retrofit) of noncomplying airplanes or by their replacement with complying airplanes. In 1980, the FAA extended the noise compliance rule to all aircraft, both U.S. and foreign operated, as a condition for use in the United States beginning in 1985.

Having established compliance requirements for current civil subsonic airplanes with the noise levels established by FAR 36 in 1969 (Stage 2), attention was then focused on lowering noise levels of new-design aircraft. In 1976, the Environmental Protection Agency (EPA) proposed phased noise reductions to apply to aircraft designed at later dates.[11] In March 1978, the FAA revised its noise standards[12] to reflect the noise reductions that were available in the more fuel-efficient, advanced-technology engines. When averaged across the fleet, the new allowable maximum noise limits (defined as Stage 3 levels) provided approximately a 5-dB reduction from the earlier Stage 2 limits.

The FAA has also promulgated regulations covering small propeller-driven airplanes. In 1974, propeller-driven airplanes with maximum certificated weights of less than 12,500 pounds were made subject to FAR 36 noise certification requirements.[13]

The above regulatory actions took advantage of the results of Federally sponsored R&D programs.[14] The predominant activity in aviation-noise-abatement research, technology development, and demonstration programs during the late 60's and early 70's was directed at reducing noise levels of the large aircraft, which make up the bulk of the commercial air carrier fleet. The significant programs of that period, the Sound Absorbent Material (SAM) demonstration program and the refan program, are now finding their ways into operational use. SAM treatment is being applied by some airlines as a retrofit to their fleets and is also incorporated in new-production aircraft as a noise-reduction measure. The technologies demonstrated in the refan and SAM programs are both used in the new DC-9-80 series aircraft, which have been designed to meet the Stage 3 FAR Part 36 noise levels.

Further application of existing technology can provide significant noise reductions for new-design turbofan powered general aviation aircraft. In addition, application of current technology to military transport and tanker aircraft can also provide substantial noise reduction. Reengining of such existing military aircraft has been considered. Joint civil/military airports can benefit from the quieter aircraft.

Although it is generally agreed that aircraft-noise control at the source is the most cost-effective way to reduce noise exposure, particularly when technological improvements are applied early in the aircraft or engine design and development cycle, there tends to be a 7- to 10-year time lag between the demonstration of a new technology and its incorporation into new designs for fleet use. Thus, 10 years or more will pass before there is sufficient replacement of the older, noisier fleet with quieter planes so as to noticeably reduce community noise exposure.

Flight Procedures

The FAA has promulgated two regulations pertaining to noise-abatement flight procedures; one addresses the sonic boom of supersonic transports (SST)[15] and the other addresses the landing-flap settings of subsonic aircraft.[16] The operator of an SST is prohibited, except over specified test routes, from conducting flight procedures that would cause the aircraft to exceed the speed of sound and thereby cause a sonic boom to reach land areas. On subsonic aircraft landing-flap settings, the operator is required to use a lower-than-maximum flap setting unless the pilot determines that weather, runway conditions, or other safety factors require the maximum. A lower flap setting requires lower thrust, which results in less noise exposure. Both of the FAA flight-procedure regulations are effective in controlling noise.

Noise-abatement takeoff procedures have been recommended by the FAA in advisory circulars.[17,18] The recommended takeoff procedures are capable of effecting substantial noise reduction.

Airport Operations

Each airport has a unique distribution of population relative to its runways. At many airports, opportunities exist for reducing noise exposure by using runways and flight tracks (flight path projected vertically to ground) that take advantage of areas that have the least residential population, such as water, industrial land, and agricultural land. The development of minimum noise-exposure flight tracks requires a coordinated effort by the airport proprietor and the FAA to reduce noise impacts while maintaining high safety standards and airport capacity. That effort may involve adjustments to flight paths for both arrivals and departures to maintain adequate separation, locating new navigational aids and additional training of both air traffic controllers and flight personnel.

Changes in flight tracks at Los Angeles International Airport reduced take-off-noise impact by requiring departing aircraft to climb out over the ocean and recross the coast at altitudes exceeding 7,500 feet. At Logan International Airport in Boston, the FAA has adopted flight tracks that make more effective use of the harbor for climbout. By increased use of the Logan runway that has the greatest potential for community noise improvement, the number of people exposed to greater than L_{dn} 65 dB has been substantially reduced.

Airport-Noise-Control Planning Programs

From the Federal perspective, airport-development and noise-control planning are primarily local concerns with the Federal role limited to providing technical assistance and financial support. The funds are provided through the Airport Development Aid Program (ADAP), which was authorized by the Airport and Airway Development Act, Amendments of 1976[19] to include, as allowable costs, "... the purchase of noise suppressing equipment, the construction of physical barriers, and landscaping for the purpose of diminishing the effect of aircraft noise on any area adjacent to a public airport,... (and) any acquisition of land or of any interest therein necessary to insure that such land is used only for purposes which are compatible with the noise levels characteristic of the operation of a public airport." That act expired in 1980 and is still being reconsidered by Congress.

In January 1981, the FAA established a new interim regulation[20] (FAR Part 150) prescribing plan requirements for airport operators who choose to develop an airport-noise-compatibility-planning program under the Federal program. That rule implements portions of Title I of the Aviation Safety and Noise Abatement Act of 1979.[21] It includes the establishment of a single system of measuring airport noise and a single system for determining the exposure of individuals to airport noise. It prescribes a standardized airport-compatibility-planning program, including the following:

1. the development and submission to the FAA of noise exposure maps and noise-compatibility programs by airport operators;

2. the standard noise methodologies and units for use in airport assessments;

3. the identification of land uses that are normally compatible (or noncompatible) with various levels of noise around airports; and

4. the procedure and criteria for FAA evaluation and approval or disapproval of noise-compatibility programs. While those rules reflect the applicable provisions of the Aviation Safety and Noise Abatement Act of 1979, they are also the outgrowth of and response to the recommended regulations submitted to the FAA by the EPA referred to as the airport noise regulatory process.[22]

The FAA conducted an airport-noise-control and land use-compatibility (ANCLUC) program[23] that preceded FAR Part 150. Some 40 airports participated in that grant program, which demonstrated noise-control planning concepts on an airport-by-airport basis. From the date of enactment of the 1976 ADAP amendments (July 12, 1976) to June 30, 1979, 29 airports submitted noise-abatement plans for review by the FAA.[23] The FAA has also issued an advisory circular on airport/land use-compatibility planning.[24]

A recent study conducted for EPA[25] documented the progress made to achieve land use compatibility at the nation's airports. Specifically, information was gathered on the kind, extent, and cost of noise-related land use actions. Information was also gathered on the benefits derived from those actions and from any operational measures that had been implemented. Airports with active noise-control programs, such as those with ANCLUC studies, were questioned.

Twenty-two of the 40 airports studied had taken land use actions for noise compatibility, spending a total of $251,260,000. Sixteen airports had made land purchases, 10 had made zoning changes, 3 bought easements, and only 1 (Los Angeles, CA) had done soundproofing (to both public and private structures). Although the cost of land was high in many instances, the preferred method of land acquisition was fee-simple acquisition. Zoning changes were often made at no cost to the airport authority. Several airports stated that they had completed their land purchases. Those and other airports expressed a desire to keep surrounding land free from residential uses.

Only six airports with no previous land use-action experience had formulated definite plans to initiate land use actions. Most of the airports that had already undertaken substantial land use actions plan future actions. Twenty-two airports have budgeted $393,900,000 for future land use changes. Twelve plan land acquisition, six plan zoning changes, and three plan soundproofing. One airport (Reno, NV) plans to spend $2.6 million on a purchase assurance plan. Two others (St. Louis, MO and Los Angeles, CA) will buy easements. Two of three airports that plan to soundproof residences and schools are older, urban airports (Pittsburgh, PA and St. Louis, MO).

Regarding operational measures, 28 airports reported taking operational measures for noise-abatement reasons. Those include two airports that plan to construct new runways at a cost of $4 to $5 million each. Three additional airports plan runway relocation, reconstruction, or extension to alleviate noise. Many other operational measures were taken, ranging from preferential runways to horizontal and vertical control to curfews. One airport installed a noise monitoring system, and another created a staff position for noise control. Only one airport (Bedford, MA) had penalties for infractions of its operational procedures.

The airport/land use-action study concluded that progress is being made at U.S. airports to permit noise/land use compatibility. Airports have spent $251 million to plan and implement land use changes that have affected 5,000 housing units. The funding for land use change has come in part from Federal grants to purchase land to soundproof and to facilitate zoning changes.

STATE ACTIONS

Several States have taken the initiative in protecting the health and welfare of their citizens from the adverse effects of aviation noise. Some examples follow.

California

California has established 65 dB measured on the community noise equivalent level (CNEL) scale as the level needed to protect people residing in the vicinity of the airport. That level is equivalent to EPA's L_{dn} 65 dB. The responsibility for adopting and enforcing the noise standards is assigned to the county in which the airport is located.

The standard states that no airport shall operate in a manner that exposes adjacent areas to noise levels in excess of 65 CNEL unless the proprietor obtains a variance. The variance process requires airport proprietors to do site-specific, time-phased planning for actions that will contribute to the improvement of the noise environment around the airport.

Maryland

The Maryland airport-noise-control program addresses the problem of off-airport/land use compatibility by attempting to minimize noise levels at existing noise-sensitive developments and by preventing the introduction of new noise-sensitive developments. Maryland's Environmental Noise Act of 1974 requires the following:

1. Airport operators must assess the off-airport-noise impact of current and projected aircraft operations.
2. If the off-airport impact exceeds L_{dn} 65 dB, a noise-abatement plan must be developed to reduce the impact on noise-sensitive land uses to the extent practicable.
3. In cases where the noise-abatement plan does not reduce the off-airport noise exposure to L_{dn} 65 dB, a state-certified airport-noise zone must be established. The zone must, at a minimum, encompass the area within the L_{dn} 65 dB contour. The State has control over land use activities within the airport-noise zone to prevent additional incompatible use.

Other States

Florida, Minnesota, and Oregon also have programs that encourage noise reduction in the airport vicinity, and Illinois is considering the adoption of a similar program. Those programs can play an important role in bringing the parties together to seek solutions and in controlling land use where the local jurisdictions are unable or unwilling to do so.

LOCAL ACTIONS

At the local level, the control of airport-noise exposure involves use restrictions imposed by airport proprietors and by compatible land use planning.

Airport Use Restrictions

Beginning in 1962, the courts placed the financial liability for aircraft-noise damages on the airport proprietors. Since the mid-70's, the courts have begun to recognize and to define the authority of the proprietors to regulate aircraft activity so as to avoid or minimize that financial liability. The authority of the proprietors to establish noise limits applicable to all types of aircraft has been upheld, as has the setting of limits applicable only in stated time periods, such as nighttime, and the control of training activities.

Use restrictions at airports are important tools for near-term reduction of noise exposure around major airports, but control of aircraft noise alone will not provide adequate relief. Ideally, such restrictions should be imposed on the basis of a thorough study of the noise levels in surrounding neighborhoods (calculated or measured) and a careful consideration of the most cost-effective and least-disruptive restrictions that will produce the desired reduction of noise levels. In recognition of the importance of airport-specific restrictions and the need for careful planning, Congress passed the Aviation Safety and Noise Abatement Act of 1979.[21]

Local Land Use Planning

Controlling the use of the land around the airport is an important means of reducing the impact of airport noise. Such land should be developed only for purposes that are compatible with airport noise. In cases where the land is already developed for incompatible uses (such as residences), special programs, including soundproofing or relocation, may be required to reduce the noise impact on users to an acceptable level.

Land use control is clearly a local matter. Theoretically, that means that local officials have the power to control local zoning, to acquire interests in land (such as development rights), to develop compatible land use guidelines, to enact building codes, and to determine airport locations. However, the local entity that develops the airport may be different from the one asked to control local land uses. The interests of the two entities may also be conflicting.

The establishment of compatible land use plans for noise-exposure control can be a very useful step toward establishing satisfactory coexistence of airports and communities if the plan is implemented before the land is developed for residential use. Such plans are especially helpful if they are prepared in conjunction with an onsite airport-noise-abatement plan that examines possible restrictions on the use and operation of the airport.

Environmental assessments or environmental impact statements must be prepared when changes or new developments requiring Federal support are proposed at an airport that may significantly affect the surrounding environment. The FAA has proposed new policies and procedures that will clarify and simplify earlier requirements for actions to be taken by airport proprietors in preparing those environmental assessments and environmental impact statements. If done well, those assessments can foster and promote compatible land use planning by local officials in conjunction with the planning for the airport development.

Funding

The funding and implementation of airport/land use-compatibility plans is a local responsibility. Some Federal ADAP funds have been made available by Congress for planning and land acquisition. In addition, the Aviation Safety and Noise Control Act of 1979 does not confine noise-project eligibility for ADAP funds to a few items as did the Airport and Airway Development Act of 1970 as amended.

Of course, where Federal funds are available, a relatively small percentage of the project cost must be provided by the airports. At some airports, land acquisition has been undertaken by using only airport-owner funds. In Atlanta, the State legislature authorized condemnation of land, within the city limits, which was in a high noise-impact area. Such land can sometimes be used quite profitably for airport associated industrial purposes. In some cases, the purchase and resale can be accomplished at a profit.

Airport proprietors may find it necessary to fund noise-control programs without Federal subsidy. Locally funded programs can include the purchase of land (or an interest therein), the management of growth patterns through zoning and utility (sewer, water) extension policies, the preservation of important land resources by means of unique tax-assessment procedures, and the soundproofing of noise-sensitive structures.

A potential source of funding of airport noise-control programs, which has yet to be used in this country, is a noise charge, that is, a charge to aircraft operators in proportion to the noise they make. Noise charges can be an incentive for aircraft operators to produce less noise and also be a source of funds for noise-abatement actions. That is an important concept in that those who make the noise and benefit from the aviation service causing it also pay for the costs that it imposes on the rest of society (the polluter pays principle). The advantage of such a concept is that it forces aircraft operators to take into account noise costs just as they now account for material and labor costs. Noise charges are now assessed in Japan, France, The Netherlands, Switzerland, and Germany. Some part of the noise charge is used to support noise-control programs, such as soundproofing of buildings.

CHAPTER 4. PROSPECTS FOR THE FUTURE

INTRODUCTION

This chapter seeks to identify areas and procedures where further progress can be made toward achieving compatibility between air carrier airports and adjoining communities. Source regulations, flight procedures, and airport operations, discussed under "Federal Actions" in the previous chapter, are reviewed for possible future benefits. Compatible land use control, discussed in the previous chapter under "State and Local Actions," is identified as the means whereby further reductions in numbers of people impacted can be accomplished when a problem remains after benefits from other means have been realized. Litigation, reviewed in Chapter 2, is also discussed in this chapter.

SOURCE REGULATIONS AND RESEARCH

The introduction of the first generation of quiet aircraft (meeting Stage 2 noise limits, established in 1969) is only now beginning to make a significant change in aircraft noise. A second generation of quiet aircraft, such as B757, and B767, using the Stage 3 technology developed during the early 70's is now being produced for service and will begin to reduce noise exposure in the mid 90's. Stage 3 technology should be fully effective in minimizing noise exposure during the early part of the next century. Although the Federal Aviation Administration (FAA) has not ruled out further source-noise regulation in the future, no further regulations are currently planned.

The quest for greater fuel efficiency has brought about renewed interest in propfan technology development. The propfan offers a potential for lower noise levels than the levels of the latest design turbofan engines. They may be used on new-design, small aircraft to be introduced into the fleet in the 90's and later. Large propfan aircraft are not expected in this century. Therefore, the impact of propfan powered aircraft by the year 2000 will be small. Small noise reductions in the next century may compensate for expected increases in enplanements that will involve either more aircraft operations or larger, noisier aircraft.

FLIGHT PROCEDURES

Noise-abatement-takeoff procedures can be tailored to the particular aircraft type using them. Noise reduction as a function of thrust reduction is much greater for older-design aircraft powered by low bypass ratio engines than for current aircraft powered by newer-design, high bypass ratio engines. Thus, thrust reduction may be used to provide substantial reductions in areas and number of people impacted by noise of aircraft powered by low bypass ratio engines, which are currently widely used. However, by 2000, aircraft powered by high bypass ratio engines will predominate. Those aircraft will produce the lowest noise impact if operated at high thrust throughout the climb. Increased altitude, that is, increased distance, will provide more noise reduction than reduced thrust. Considerable variation in takeoff flight procedures among the different airlines is believed to exist, based on available noise measurements. Minimum noise-exposure-takeoff flight procedures should be encouraged as a means of reducing noise impact from flights over residential areas since benefits would be immediate.

AIRPORT OPERATIONS

In many cases, it is possible for aircraft after takeoff to turn away from densely populated areas, thereby significantly reducing the number of people impacted by aircraft noise. That procedure involves the use of a priority runway system and curved flight tracks (vertical projections of flight paths on the ground). The procedures are in use at some airports and are being developed at others. The noise-reduction benefits of using priority runways and curved flight tracks are also immediate.

COMPATIBLE LAND USE CONTROL

For many airports, a residual population impacted by aircraft noise will remain after the benefits from noise-abatement flight procedures and airport operations have been realized. A further reduction in number of people impacted can be accomplished by airport/land use-compatibility planning and implementation.

REQUIREMENT OF FAR PART 150

In the Aircraft Safety and Noise Abatement Act of 1979 (PL-96-193), the Congress instructed the FAA to provide standards for voluntary airport/land use-compatibility planning to be supported by Federal funding. Those standards, published as FAR Part 150, require the identification of land uses within the L_{dn} 65-dB noise-impact area that are not compatible with noise exposure above L_{dn} 65 dB. Residential use is listed as one of those uses. The document, however, provides the following dis-claimer:

> "The designations contained in this table (in which non-compatible uses are listed) do not constitute a Federal determination that any use of land covered by the program is acceptable or unacceptable under Federal, state or local law. The responsibility for determining the acceptable and permissible land uses remains with the local authorities. FAA determinations under Part 150 are not intended to substitute federally determined land uses for those determined to be appropriate by local authorities in response to locally determined needs and values in achieving noise compatible land uses."

California and Maryland have state laws that have essentially the same land use-compatibility standards as FAR Part 150. Other states are developing similar legislation.

LAND USE-CONTROL ACTIONS

To develop a noise-compatibility plan, the airport operator must first predict the area and number of people that will be exposed to various levels of aircraft noise. For an anticipated number and mix of aircraft, that will be a function of various procedural and operational actions that can be taken to control the noise and the land use on a specified date in the future. After all feasible cases have been considered, there may still be residential areas above L_{dn} 65 dB on the desired target date. If that occurs, land use change in those residual areas must be used to achieve compatibility.

Since the area around most major airports exposed to aircraft noise above L_{dn} 65 dB is already developed for residential use, zoning will not be an important tool in achieving compatibility. Even in areas that are not highly developed, zoning may not be a reliable tool, since it is subject to changes. The purchase of easements on underdeveloped land is recommended instead.

For residentially developed land exposed to noise above L_{dn} 65 dB, soundproofing is the most practical and cost-effective step that can be taken to achieve compatibility. However, in areas above L_{dn} 65 dB, relocation may be required.

Soundproofing/Relocation Considerations

To achieve practical airport noise/land use compatibility at minimal cost, it is necessary to know the costs of land use change in areas that will have noise exposure above L_{dn} 65 dB for the foreseeable future. The changes considered in Chapter 6 of this report are soundproofing houses to achieve interior noise levels of L_{dn} 45 dB (levels normally existing with exterior levels of L_{dn} 65 dB) and the removal of families from areas where the noise levels will remain above L_{dn} 75 dB for the foreseeable future. The specific features of any particular plan must be determined at the local community level, depending on local conditions.

LITIGATION

When the airport proprietors, neighbors, and local governments are unable to resolve their conflicts, they turn to the courts for resolution. Based on the history of airport-noise litigation, further legal actions in that area may be expected in the future. Chapter 2 of this report provides background information and further insight regarding prospects for future litigation.

A recent conference[26] on airport noise found airport operators recommending negotiations with surrounding communities. The operators suggested that it is best to be candid concerning the prospects for noise reductions and to be open to any suggestions for reducing noise impact by airport procedures. They felt that after a case goes to court, they lose control and the result may be detrimental to everyone.

CHAPTER 5. DEVELOPMENT OF NOISE-EXPOSURE ESTIMATES

INTRODUCTION

To evaluate the effect and cost of measures that could be employed to provide relief to airport-noise-impacted residents, a methodology[27] was developed to integrate the parameters affecting noise exposure.

The methodology involves developing representative airports, calculating noise exposure for those airports, and scaling the results to derive national noise-exposure estimates to the year 2000. Using representative airports (Rports) permits forecasts to be generated with variables such as fleet size, fleet composition, flight procedures, and flight paths by studying only a representative sample of airports instead of the entire air carrier airport population.

Each Rport represents one of a number of distinct categories of airports. The noise exposure around an Rport, specified in terms of area and population exposed (as well as other pertinent socioeconomic and demographic considerations), approximates the total noise exposure for all of the airports within the category it represents when multiplied by an appropriate scaling factor. Also, the sum of the noise exposures for all categories approximates the total noise-exposure area and population of all air carrier airports.

Development of a methodology based on the Rport concept required collection of a comprehensive data base to be used for the following:

1. definition of airport categories,
2. selection of Rports in each category,
3. generation of noise-exposure values at Rports, and
4. extrapolation of pertinent parameters to future years.

The analytical tools discussed in this chapter were used to generate reference noise-exposure estimates for 1979, 1990, and 2000. Reference exposure estimates were made for Rports from which national estimates were obtained. Those exposure values are used as a reference for noise-exposure-reduction studies covered in Chapter 6.

IDENTIFICATION AND GENERATION OF REQUIRED DATA BASES

The identification and generation of the data bases required to define airport categories and to select a single airport that represents each of those categories were divided into two parts:

1. the development of an airport/aircraft data base that could be used to define distinct categories (or sets) of airports and
2. the development of an airport/aircraft data base needed as input to two computer models:
   a. the Federal Aviation Administration's (FAA) integrated noise model (INM)[28] and
   b. the National Aeronautics and Space Administration's (NASA) aircraft-noise-levels annoyance model (ALAMO).[29] When used with the data for selected airports in each category, the INM/ALAMO outputs provided the basis for selection of the Rport representative of its category.

Data Used to Define Categories of Airports

The airport/aircraft data indentified as being required for developing distinct categories of airports included the following:

1. number of annual commercial jet air carrier operations for each airport considered,
2. airport noise produced by the flight operations of specific commercial jet air carrier aircraft,
3. selected socioeconomic and demographic variables that describe the surrounding airport community (population, housing type, owner/renter-income data, etc.), and
4. airport/aircraft parameters that are specific to each airport considered.

Number of Annual Commercial Jet Air Carrier Operations. This variable was considered essential because it is one of the determinations of the total noise produced by aircraft operations. The number of annual (calendar year 1979) commercial jet air carrier departures by aircraft type was obtained from FAA data[30] and is, henceforth, referred to as the airport activity statistic (AAS) file. It included data for 304 airports serving certified route air carriers.

Airport Noise Produced by Commercial Jet Air Carrier Operations. The airport noise produced by commercial jet air carrier operations was represented by two noise measures: airport noise index (ANI)[31] and fleet-noise level (FNL). The ANI takes into account both the noise generated by each aircraft and the number of operations of each aircraft. It is sensitive to the aircraft-noise total energy that is received on the ground and approximates the day/night sound level calculated without nighttime weighting. The concept of FNL provides a method for evaluating the noise status of fleets of aircraft. It provides a single figure of merit so that fleets of aircraft can be compared with each other on the basis of noise. That comparison is computed by the following equation:

$$\text{ANI} = \text{FNL} + 10 \log (d/365) + 53$$

where: ANI = airport-noise index in dB
FNL = fleet noise level in dB
d = number of yearly departures

The FAA provides information on noise levels produced by all aircraft in service in the U.S. airline fleet at the three measuring points specified in Federal Air Regulation (FAR) Part 36. Values of FNL were found for each of the FAR Part 36 measuring points for each airport. ANI values corresponding to each FNL were then calculated.

Selected Socioeconomic and Demographic Variables. In addition to the aircraft operations and noise-level data, consideration of certain socioeconomic and demographic variables was necessary in developing distinct categories of airports. The airport selected was presented not only in terms of noise levels, but also in terms of population exposed to the demographic characteristics of this population. That information was used to project national and airport-specific benefits of noise-control actions.

The variables selected for inclusion in the aircraft/airport data base were obtained from the FAA's airport information file (AIF).[32] The following variables were included:

1. total population,
2. number of households in 1975,
3. total number of incomes,
4. total number of homes,
5. total number of renters,
6. average home value,
7. average monthly rent,
8. population change from 1970 to 1975, and
9. population growth rate.

Values for each of the variables were determined for areas within a 5-mile and a 10-mile radius of the airport center using the latest available census data, except where indicated otherwise.

Airport/Aircraft Parameters Specific to Each Airport. A number of additional airport-specific variables were obtained from the AIF and included in the airport/aircraft data base.

Combined Airport/Aircraft Data Base. The airport/aircraft data obtained from the AIF and the AAS file were combined to form a single data base. The number of airports contained in the data base was limited to 236 by including only those airports that handled four or more scheduled large jet (greater than 75,000 pounds) operations per day. Those airports accounted for over 10 million air carrier operations performed in calendar year 1979 (about 95 percent of the total jet operations).

Input Data Required to Run the FAA's Integrated Noise Model (INM)

The INM is a computer model that can be used to calculate the aircraft-noise environment in the vicinity of an airport given information concerning airport location and layout, aircraft types and air traffic movement. The resulting noise environment is described in Figure 5-1.

The INM user is required to provide at least 5 and up to 10 kinds of data describing the airport and its associated activity to run the model. Required data include the following:

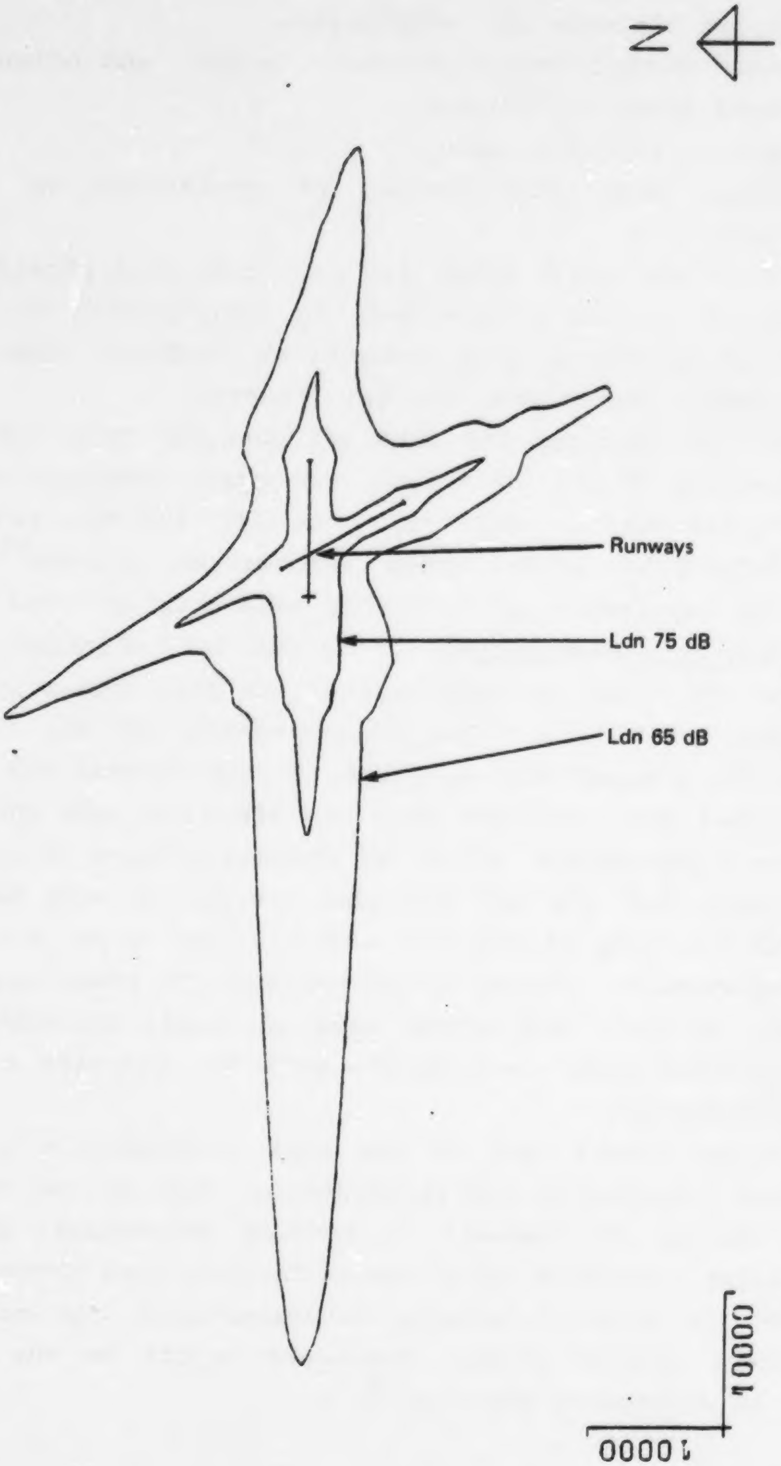
N
Runways
Ldn 75 dB
Ldn 65 dB
10000
10000

FIGURE 5-1. EXAMPLE OF GRAPHIC PRESENTATION OF INM RESULTS

1. airport altitude and temperature,
2. runway configuration (number, length, and orientation),
3. ground track definition,
4. approach profiles, and
5. traffic mix (distribution of operations by aircraft type).

In addition to the above data, the user must also provide information related to runway use and the distribution of aircraft operations by operation type (takeoff or landing), time of day, and, for takeoff operations, the trip length.

Most of the required INM data was obtained from the AIF and the AAS computer files. Data base management programs were used to extract information from both the AIF and the AAS and to generate data base files. Other information sources[33,34] were also used to supplement or to verify data obtained from the AIF.

INM Input Data Preparation. Using the data obtained from the AIF and the AAS files, aircraft operations data were computed for each airport considered. The determination of the number of operations for a given aircraft type at each airport was based on the operations data obtained from the AAS file, and the distributions (on a percentage basis) of operations were obtained from the AIF. Note that the AIF provided operations data related to trip length and time of day for each aircraft type, but did not provide information related to runway use. In preparing the INM data bases, aircraft operations were uniformly distributed over all runways that were commensurate with the aircraft's performance characteristics.

The ground tracks used in INM runs to establish a baseline were assumed straight-in and straight-out, that is, no turns were performed during the takeoff or landing operations. Also, the takeoff flight procedure and noise technology were those internal to the INM for airport-category determinations. For noise-exposure studies, takeoff flight procedure inputs to the INM were generated by a computer program.[35]

A standard 3° glide slope was assumed for landing operations. The thrust and velocity parameters used with the standard 3° glide slope landing procedure are part of the INM's internal data.

Input Data Required to Run the ALAMO. The ALAMO is an airport community noise-impact-assessment model[29] currently operational on the NASA Langley Research Center's (LRC) computer system. For a given INM input, ALAMO will provide area, population, and number and types of residences within L_{dn} bands 5-dB wide around an airport.

A complete INM data base is one input required to run the ALAMO. Other required inputs include the latitude and longitude of the airport center (obtained from the AIF), the state in which the airport is located, and two adjacent states. Using those data, ALAMO uses a demographic retrieval system called SITE II (a proprietary demographic data base developed by CACI, Inc.) to obtain a variety of community demographic information based on the 1970 Census of Population and Housing.

AIRPORT-CATEGORY DETERMINATION

Factor analysis and other mathematical techniques were used to select significant variables and to place the 236 airports in the data base in 6 airport categories, labeled A through F, with similar characteristics. The variables considered in that placement included number of air carrier operations, airport noise produced by those operations, selected socioeconomic and demographic variables, and airport/aircraft parameters specific to each airport. The two smallest airport categories, E and F, did not have large enough populations above L_{dn} 65 dB to significantly affect the total population of interest. Therefore, they were not considered further. The number of airports was thereby reduced to 129.

SELECTION OF REPRESENTATIVE AIRPORTS

The selection of Rports was made on the basis of the area and population exposed to various noise levels. Those areas and populations were generated by ALAMO.

Of the 129 airports in the remaining 4 categories, 55 were selected for ALAMO computer runs. The distribution of those airports by Rport category is listed in Table 5-1. Those included all airports in categories A and B that had relatively large areas within the L_{dn} 65- to 75-dB contours and smaller percentages of airports in the C (45-percent) and D (28-percent) categories.

TABLE 5-1. DISTRIBUTION BY RPORT CATEGORY

Rport Category	Number of Airports in the Category	Number of Airports Selected for ALAMO Runs
A	13	13
B	1	1
C	44	21
D	71	20
TOTAL	129	55

Table 5-2 shows the distribution of the 129 airports by category and identifies the airports selected for ALAMO computer runs.

The ALAMO noise-exposure reports for each of the 55 airports were used to determine the contour areas and the population enclosed within equal bands of L_{dn} 65 dB and L_{dn} 75 and greater. The Rport selected to represent each category was determined by comparing area and population of these two contour bands for each airport in the category and by selecting the airport with values closest to the mean of the category.

The airports selected to represent each category were the following:

Airport Category	Representative Airport
A	Miami, FL (MIA)
B	La Guardia, NY (LGA)
C	San Antonio, TX (SAT)
D	Sioux Falls, SD (FSO)

TABLE 5-2. DISTRIBUTION OF AIRPORTS BY AVPORT CATEGORY

AVport Category	APT ID.	Location
A	ATL	Atlanta, GA*
	DFW	Dallas, TX*
	LAX	Los Angles, CA*
	ORD	Chicago, IL*
	DEN	Denver, CO*
	JFK	New York, NY*
	SFO	San Francisco, CA*
	EWR	Newark, NJ*
	BOS	Boston, MA*
	DCA	Washington, DC*
	MIA	Miami, FL**
	STL	St. Louis, MO*
	PHL	Philadelphia, PA*
B	LGA	New York, NY**
C	BDL	Windsor Lock, CT*
	BNA	Nashville, TN*
	BUF	Buffalo, NY
	BWI	Baltimore, MD*
	CLE	Cleveland, OH
	CLT	Charlotte, NC
	CVG	Cincinnati, KY*
	DAY	Dayton, OH*
	DTW	Detroit, MI
	ELP	El Paso, TX
	FLL	Ft. Lauderdale, FL*
	HNL	Honolulu, HI
	IAD	Washington, DC
	IAH	Houston, TX
	IND	Indianapolis, IN*
C	JAX	Jacksonville, FL
	LAS	Las Vegas, NV
	MCI	Kansas City, MO
	MCO	Orlando, FL*
	MEM	Memphis, TN*
	MKE	Milwaukee, WI
	MSP	Minneapolis, MN
	MSY	New Orleans, LA*
	OAK	Oakland, CA
	OKC	Oklahoma City, OK*
	OMA	Omaha, NB
	PBI	West Palm Beach, FL*
	PDX	Portland, OR*
	PHX	Phoenix, AZ
	PIT	Pittsburgh, PA
	RNO	Reno, NV
	SAN	San Diego, CA
	SAT	San Antonio, TX**
	SDF	Louisville, KY
	SEA	Seattle, WA*
	SJC	San Jose, CA
	SLC	Salt Lake City
	SMF	Sacramento, CA
	SYR	Syracuse, NY*
	TPA	Tampa, FL*
	TUL	Tulsa, OK*
	TUS	Tucson, AZ*
	ABQ	Albuquerque, NM*
	ANC	Anchorage, AK
D	ALB	Albany, NY
	BTV	Bulrington, VT
	BUR	Burgank, CA
	CAK	Akron, OH
	CMI	Champaign/URB, IL
	DAL	Dallas, TX
	FAI	Fairbanks, AK
	GRR	Grand Rapids, MI
	GSO	Greensboro, NC
	HPN	White Plains, NY
	ITO	Hild, HI
	JAN	Jackson, MS*
	JNU	Juneau, AK
	KTN	Ketchikan, AK
	LEX	Lexington, KY*
	LGE	Long Beach, CA
	LIH	Lihue, HI
	MDW	Chicao, IL
	MSN	Madison, WI*
	OGG	Kahului, HI
	PSP	Palm Springs, CA
	SBA	Santa Barbara, CA
	SNA	Santa Ana, CA
	AUS	Austin, TX
	MLI	Moline, IL*
	MOB	Mobile, AL
	PVD	Providence, RI
	DSM	Des Moines, IA*
	HOU	Houston, TX

*Denotes airports selected for ALAMO computer runs

**Denotes AVport

TABLE 5-2 - CONTINUED. DISTRIBUTION OF AIRPORTS BY AVPORT CATEGORY

AVport Category	APT ID.	Location
D	LAN	Lansing, MI*
	BIL	Billings, MI*
	CRW	Charleston, SC
	BIS	Bismark, ND
	BOI	Boise, ID*
	FAR	Fargo, ND
	GRB	Green Bay, WI
	COS	Colorado Springs, CO*
	SRQ	Sarasota, FL*
	CAE	Columbia, SC
	ICT	Wichita, KS
	SHV	Shreveport, LA
	TOL	Toledo, OH*
	FMY	Ft. Meyers, FL
	GEG	Spokane, WA
	LIT	Little Rock, AR
	RIC	Richmond, VA
	MBS	Saginaw, MI0
	TRI	Bristol, TN*
	BTR	Baton Rouge, LA
	CID	Cedar Rapids, IA*
D	CHA	Chattanooga, TN
	DAB	Daytona Beach, FL
	FSD	Sioux, Falls, SD**
	ONT	Ontario, CA
	PWM	Portland, ME*
	BHM	Birmingham, AL
	FAY	Fayetteville, NC*
	GTF	Great Falls, MT
	AVL	Ashville, NC
	FNT	Flint, MI
	PIA	Peoria, IL
	TLH	Tallahassee, FL
	ORF	Norfolk, VA
	ROC	Rochester, NY
	EUG	Eugene, OR*
	RDU	Raleigh-Durham, NC
	ROA	Roanoke, VA
	TYS	Knoxville, TN
	ABE	Allentown, PA
	FAT	Fresno, CA
	CHS	Charleston, WV

DEVELOPMENT AND PROJECTION OF DATA

Fleet Forecast

Since the projected aircraft mix and number of aircraft operations have a direct bearing on the level of community-noise exposure, the fleet mix was developed for base year 1979 and forecast years 1990 and 2000. A moderate 1.7-percent annual growth rate for total aircraft was used. As new aircraft types are introduced into fleet service, they will replace older types that are not only noisier and less fuel efficient, but also have lower seat capacities. As shown in the Table 5-3, the average seats per aircraft is estimated to increase by 104 percent between 1979 and 2000. While the number of commercial aircraft is estimated to increase only by 42 percent, the larger capacity aircraft expected in 2000 require fewer annual departures than the 1979/1990 aircraft to handle any given passenger demand level. Thus, a decrease in departures in 2000 is indicated. Total seat capacity is projected to increase from 372,000 in 1979 to 1,082,000 in 2000, a 191 percent increase.

TABLE 5-3. AIR CARRIER FORECASTS

	Baseline	Forecast Year	
	1979	1990	2000
Number of Aircraft	2,384	2,870	3,397
Average Number of Seats per Aircraft	156	231	319
Number of Departures in Thousands	4,606	4,777	4,394

Projections of Aircraft Operations

Air carrier activity was projected for each of the four airport categories and then by specific airport. Total fleet departures were determined as the product of the number of aircraft obtained from FAA Aviation Forecasts[37] and the applicable aircraft productivity factor (APF)*. Departures for each category

---

$$*\text{APF} = \frac{\text{Departures}}{\text{Number of aircraft}}$$

were determined by adding the departures for each airport contained within each category.[30] Airports contained in the four categories composed 62 percent of the national air carrier departures in baseline year 1979. That same percentage was then applied to determine the total departures for each of the two forecast years.

The total departures were then allocated to each of the categories. That was done by a subjective adjustment of the baseline 1979 departure data. Consideration was given to the general nature of airport operations, such as hub versus terminal and to the type and mix of aircraft that might be handled by each airport given its operational constraints such as adequate runway length to accommodate wide-bodied jets. Since an Rport is representative of all airports within its category, departures were determined by dividing category departures by the total number of airports in that category. The results of that procedure are summarized in Table 5-4.

Demographic Forecasts

Housing, population, and other demographic factors of communities around airports have not remained static in the past, nor are they expected to remain so in the future. For example, many noise-impacted communities (defined by noise-contour bands) experienced different growth rates for population and residential units during the 1970's. Increased divorce rates, reduced or deferred marriages, and fewer children per family led to smaller household sizes requiring more housing to accommodate a given population level. Those and other changes were captured by updating selected demographic variables, primarily, by using data on growth rates for population and households. Airport-specific demographic profile reports were generated by the ALAMO program for each noise-level contour band (L_{dn} bands 55-60 dB, 60-65 dB, 70-75 dB, 75-80 dB, 80-85 dB, 85+ dB, 65-75 dB, and 75+ dB).

The ALAMO data used were from the 1970 census. Predicted census data for 1977 were used to obtain growth rates. Projections to 1979, 1990, and 2000 were developed from those two census data points. Procedure details are given in reference 38.

Noise-Exposure Estimates

Data base noise exposures were calculated for the four representative airports and the four categories of airports using the methodology described. The population exposed to L_{dn} 65-75 dB and to over L_{dn} 75 dB is given in Table 5-5 for 1979, 1990, and 2000. Calculations were made using FAA A/C 91-39 takeoff-procedure, flight-path, and performance data as INM input.

The results of summarizing the data in Table 5-5 to arrive at a national airport-noise-exposure data base are shown in Table 5-6.

The total for year 2000 of 3.63 million is slightly higher than the value of 3.58 million previously estimated[39] for year 2000. However, the 1979 total of 7.34 million is approximately 15 percent above the previous estimate[39] for year 1975 of 6.17 million. The difference in the estimates is attributed to the methodologies used.

The present estimates were intended to provide a reference or data base from which changes could be studied. Aircraft operations were assumed to be uniformly distributed over all runways commensurate with the aircraft's performance. Flight tracks were assumed to be straight-in/out (no turns during takeoff or landing operations). Actual airport operations vary considerably from those assumptions.

TABLE 5-4. PROJECTIONS OF AIRCRAFT DEPARTURES

(Thousands)

Rport/Rport Category	BASELINE	FORECAST YEAR	
	1979	1990	2000
Miami, FL			
Category Departures	1234	1249	1112
Percent*	43.2	42	21
Rport Departures	94.9	96	85.6
New York NY (La Guardia)			
Category Departures	111	118	109
Percent*	3.9	4	4
Rport Departures	111	118	109
San Antonio, TX			
Category Departures	1156	1224	1139
Percent*	40.5	41.2	42
Rport Departures	26.3	27.8	25.9
Sioux Falls, SD			
Category Departures	355	380	353
Percent*	12.4	12.8	13
Rport Departures	5	5.4	5
Total Category Departures	2856	2971	2713
Total National Departures	4606	4777	4394

*Percent of total category departures.

TABLE 5-5. AIRPORT-CATEGORY DATA BASE NOISE-EXPOSURE ESTIMATES

Airport	Category	Year	Exposed Population L_{dn} 65-75 dB	Exposed Population 75 L_{dn} dB	Airports in Category	Category Exposed Population Over L_{dn} 65-75 dB	Category Exposed Population Over 75 L_{dn} dB
Miami, FL	A	1979	216,001	13094	13	2,592,012	170,222
	A	1990	166,126	7165	13	2,159,638	93,145
	A	2000	95,933	2485	13	1,247,129	32,305
LaGuardia, NY	B	1979	1,337,364	83569	1	1,337,364	83,569
	B	1990	811,157	46787	1	811,157	46,787
	B	2000	171,098	15243	1	171,098	15,243
San Antonio, TX	C	1979	64,241	1586	44	2,826,604	69,784
	C	1990	40,354	1634	44	1,775,576	71,896
	C	2000	41,654	27	44	1,832,776	1,188
Sioux Falls, SD	D	1979	2,643	987	71	187,653	70,077
	D	1990	3,032	1075	71	215,272	76,325
	D	2000	3,355	1275	71	238,205	90,525

TABLE 5-6. DATA BASE NATIONAL ESTIMATES OF POPULATION EXPOSED TO NOISE FROM AIR CARRIER AIRCRAFT

Outdoor Exposure Level (dB)	Number of People Exposed (Thousands) 1979	1990	2000
L_{dn} 75 or greater	394	288	139
Between L_{dn} 65 and L_{dn} 75	6,944	4,962	3,489
Total: L_{dn} 65 or greater	7,338	5,250	3,628

CHAPTER 6. NOISE-EXPOSURE REDUCTION AND COMPATIBILITY COSTS

INTRODUCTION

This chapter presents the results of a noise-exposure-reduction analysis that applies the noise-reduction methods covered in Chapter 4 to four airports, using the methodology covered in Chapter 5, and provides cost estimates for achieving compatibility by soundproofing and change of land use to non-residential. An analysis that covers cost per enplaned passenger is included.

Noise-exposure reductions from the data base are anlayzed. They include noise-abatement takeoff flight procedures, priority runways, and curved flight tracks. After those measures have been used in the analysis to reduce noise exposure, the remaining residences exposed to L_{dn} 65 dB and greater are considered for change to compatible land use.

NOISE-REDUCTION METHODS

Flight Procedures

Takeoff flight procedures involving the scheduling of flap retraction, acceleration, rate of climb, and amount of thrust reduction were studied. In addition to the data base takeoff procedure (based on AC 91-39), which does not reduce thrust below climb thrust, two additional procedures were used, based on Federal Aviation Administration (FAA) flight procedure AC 91-53. Procedure AC 91-53 involves an acceleration after initial climb, followed by a flap retraction and then by a maximum or minimum thrust reduction below climb thrust to provide a greater noise reduction beyond that point. Studies were made using the 1979 data base air carrier aircraft fleet and with fleet projected to the year 2000.

Priority Runways and Curved Flight Tracks

In a study using flight procedure AC 91-39, calculations were made for 10 airports to determine the percent reduction of the number of people impacted within specified contours when priority runways and curved flight tracks were used. Those airports included the four representatives airports. Results were used to estimate a reduction in the number of people exposed nationally.

In developing a runway priority system for an airport, the population distribution within the L_{dn} 65-dB contour was studied. The study was made using U.S. Geological Survey maps that identified urban areas and individual buildings. The selection of the first priority runway is obvious if the extended centerline of one runway is over water, swamp, desert, or underdeveloped farmland while the others are over urban areas. However, if the urbanization is equal in all directons, there is nothing to be gained by using one runway more than another.

The runways were identified as first priority, second priority, third priority, etc., on the basis of minimizing the number of people within the L_{dn} 65dB contour. The distributions of operations on those runways are based on wind velocity and direction. The FAA has determined that aircraft may use a priority runway until the tail wind exceeds 5 knots or the crosswind exceeds 15 knots.[40] Information on wind velocity and direction was obtained from the Department of Commerce Airport Climatological Summaries for each airport.[41]

In many cases, it is possible for the aircraft to turn away from densely populated areas and thereby significantly reduce the number of people exposed. Curved flight tracks were used in conjuction with priority runways developed on the basis of visual inspection of 10 Geological Survey maps of areas surrounding airports in categories A, B, and C. Turns were made only at altitudes, airspeeds, and bank angles no greater than recommended in advisory circular 91-53.[18] Calculations were made using the ALAMO program[29] to determine the reduction in the number of people exposed.

Compatible Land Use

Even after flight operations and the equipment serving a particular airport are optimized and after future encroachment (additional residences built in high noise-impact areas) is controlled, there will be a significant number of people exposed to L_{dn} 65 dB or greater through the year 2000. Relocation of those exposed to L_{dn} 75 dB or greater and soundproofing for houses located in environments of L_{dn} 65 to 75 dB was then considered to provide those people with less noise exposure inside their residences.

Selection of L_{dn} 75 dB and above as the basis for relocation was based on the assumption that people would spend time outdoors in their lawns, gardens, etc. However, it can be assumed that residents of apartment houses without outdoor recreation facilities will not spend time outdoors near their residences. Thus, residents of those buildings will not have to be relocated from areas having outside levels of L_{dn} 75 dB and above if soundproofing can achieve the desired inside levels of L_{dn} 45 dB.

In-depth studies were recently conducted by EPA that provide a basis for estimating the costs associated with relocation of residents and soundproofing of residences.[42,43] Those studies were used to estimate costs for the four representative airports considered in this report. They also provide a basis for estimating soundproofing and relocation costs for any U.S. airport. Summaries of those studies are given in Appendices A and B.

EXPOSURE-REDUCTION ANALYSIS

Noise-exposure-reduction and cost analyses were conducted for four airports, each representing a typical airport in a category of airports having operational (number and types of aircraft) and surrounding demographic (distribution of population and residences) characteristics representative of airports of various sizes. To estimate the benefit nationally of the use of priority runways and curved flight tracks, an additional six airports were studied. The 10 airports studied covered cases ranging from a maximum to a minimum reduction in noise exposure.

The following factors were considered in that analysis:

1. change in aircraft fleet composition and number of aircraft operations,
2. changes in number of people and housing units in the area within the L_{dn} 65-dB contours,
3. changes in flight procedures,

4. changes in distribution of aircraft operations on runways and the use of curved flight tracks, and
5. change in the noise exposure level (from L_{dn} 75 dB to L_{dn} 80 dB) as the basis for relocation of people who do not have outdoor areas near their residences in which they can spend time.

Factors 1, 2, and 5 are covered in Chapter 5. Factors 3 and 4 are discussed in the preceding section of this chapter. The information on airport operations and the demographic data for the area surrounding the airport were obtained from the FAA reports "Airport Activity Statistics of Certified Route Air Carriers"[30] and "Aviation Forecasts" [37] and from the U.S. Census Bureau data available from the ALAMO program.[29] Those data were not discussed with the operators of the four airports selected as representative of airport categories. Therefore, there may be some discrepancies between the data presented for those airports and the actual situation. When soundproofing houses and relocating residents, the operations and demographics must be studied in greater depth than was done in this analysis.

Two basic land use-control scenarios were studied at each of the four airports: uncontrolled residental encroachment and land use controls applied after 1979 to prevent additional residential encroachment. The analyses also considered the effectiveness of universally employing noise-abatement flight procedures and optimizing the aircraft departure flight tracks.

Three time periods were examined for each airport: 1979, 1990, and 2000. The intermediate year, 1990, was selected to examine the benefits resulting from the required retrofit or replacement of all the noisiest aircraft.

At each airport, the amount of area, number of people, and number of residential units exposed to the following average annual L_{dn} ranges (noise contour areas) were studied for the three time periods: 65 to 75 dB, 65 to 80 dB, greater than 75 dB, and greater than 80 dB. The National Aeronautics and Space Administration (NASA) Langley ALAMO program, discussed in Chapter 5, was used to generate those outputs. Those data were then used to generate costs for soundproofing[43] residences exposed to L_{dn} 65 to 75 dB and to L_{dn} 65 to 80 dB, and costs of relocating[42] residents exposed to greater than L_{dn} 75 dB and to greater than L_{dn} 80 dB.

The results of the studies for each airport for the time periods examined are summarized in Table 6-1, which gives the population exposed within the four aforementioned noise-contour areas for five scenarios, including the two basic land use control scenarios. Costs for the scenarios are also given for soundproofing residences in the L_{dn} 65- to 75-dB bands and for relocating residents in the above-L_{dn} 75-dB areas. Similarly, costs are given for two airports for soundproofing residences in the L_{dn} 65-80-dB bands and for relocating residents in the above-L_{dn} 80-dB areas. A data base case is given for 1979, 1990, and 2000 (0-R). The various scenarios are identified by number.

Flight Procedures

Table 6-1 shows that in 1979, using flight procedure AC 91-53 with maximum thrust reduction substantially reduces the population within the L_{dn} 65- to 75-dB and L_{dn} 65- to 80-dB contours from the data base case for all airports except Sioux Falls. (Compare 0-R and 1-FP.) Population exposed to over L_{dn} 75 dB and to over L_{dn} 80 dB is increased. Total population exposed to above L_{dn} 65 dB is substantially reduced from the data base when using the AC 91-53 takeoff flight procedure. Use of that procedure will provide much less exposure reduction in 1990. Calculations made for the year 2000 showed that exposure reduction would be insignificant. The explanation for those changes is discussed in Chapter 4. Significant reductions in noise exposures due to noise-abatement flight procedures are immediate.

Representative Airports

General conclusions were drawn for each airport from Table 6-1. Those conclusions basically pertain to all of the airports in the category represented by each airport examined.

TABLE 6-1. AIRPORT-NOISE-EXPOSURE REDUCTION AND COSTS

Miami, FL (MIA)

Year and Airport Scenario	Population Exposed L_{dn} 65-75 dB	Population Exposed Over L_{dn} 75 dB	Soundproofing, Relocation Cost[a]	Population Exposed L_{dn} 65-80 dB	Population Exposed Over L_{dn} 80 dB	Soundproofing, Relocation Cost[a]
1979						
0-R*	216,000	13,100	336,600	227,800	1,300	185,200
1-FP	125,600	22,200	399,400	146,000	1,800	179,900
2-FT	63,800	4,300	192,900	68,100	2,800	93,200
1990						
0-R	166,100	7,200	221,500	171,900	1,400	170,000
1-FP[b]	110,000	11,900	247,300	120,200	1,700	140,400
3-RD	142,900	6,100	183,100	147,800	1,200	138,800
4-RD+FP[b]	96,000	11,400	228,400	105,900	1,500	122,500
5-RD+FT	42,200	5,300	94,900	44,500	3,000	74,600
2000						
0-R	95,900	2,500	109,800	96,700	1,700	104,500
3-RD	69,100	1,700	73,500	69,600	1,200	70,300
5-RD+FT	20,400	1,500	33,700	20,800	1,100	29,200

* R - Reference data base
FP - Flight procedure, FAA AC 91-53, maximum thrust reduction
RD - Residential development restricted to prevent encroachment after 1979 (land use)
FT - Selected flight tracks and priority runway use

a - Cost in Constant 1979 Dollars/1000.
b - Interpolated, 1979 - 2000

TABLE 6-1. - CONTINUED. AIRPORT-NOISE-EXPOSURE REDUCTION AND COSTS

LaGuardia, NY (LGA)

Year and Airport Scenario	Population Exposed L_{dn} 65-75 dB	Population Exposed Over L_{dn} 75 dB	Soundproofing, Relocation Cost[a]	Population Exposed L_{dn} 65-80 dB	Population Exposed Over L_{dn} 80 dB	Soundproofing, Relocation Cost[a]
1979						
0-R*	1,337,300	83,600	1,374,000	1,403,300	171,600	839,100
1-FP	736,600	112,500	1,377,600	822,000	27,100	610,800
2-FT	961,000	40,200	794,100	990,800	10,400	565,900
1990						
0-R	811,100	46,800	804,700	851,500	6,400	483,700
1-FP	440,400	61,600	757,600	487,700	14,300	355,800
2-FT[b]	563,400	21,900	454,300	581,700	3,600	314,900
2000						
0-R	171,100	15,300	195,600	183,700	2,700	124,000
2-FT	123,800	7,000	109,200	129,200	1,600	84,400

* R - Reference data base
FP - Flight procedure, FAA AC 91-53, maximum thrust reduction
RD - Residential development restricted to prevent encroachment after 1979 (land use)
FT - Selected flight tracks and priority runway use

a - Cost in constant 1979 dollars/1000.
b - Interpolated, 1979 - 2000

TABLE 6-1. - CONTINUED. AIRPORT-NOISE-EXPOSURE REDUCTION AND COSTS

Year and Airport Scenario	San Antonio, TX (SAT) Population Exposed L_{dn} 65-75 dB	San Antonio, TX (SAT) Population Exposed Over L_{dn} 75 dB	San Antonio, TX (SAT) Soundproofing, Relocation Cost$_a$	Sioux Falls, SD (FSD) Population Exposed L_{dn} 65-75 dB	Sioux Falls, SD (FSD) Population Exposed Over L_{dn} 75 dB	Sioux Falls, SD (FSD) Soundproofing, Relocation Cost$_a$
1979						
0-R*	64,240	1,590	52,500	2,640	900	7,880
1-FP	42,000	3,860	95,800	3,730	890	7,670
2-FT	24,650	10	15,900	90	890	5,590
1990						
0-R	40,350	1,640	63,600	3,030	1,070	7,890
1-FP$_b$	41,820	1,850	68,900	3,530	1,090	7,890
3-RD^b	28,980	1,360	47,900	2,640	890	6,640
4-RD+FP$_b$	31,000	1,840	56,500	3,140	890	6,670
5-RD+FT^b	11,120	10	9,900	90	800	5,050
2000						
0-R	41,650	30	44,400	3,360	1,280	8,350
3-RD	21,000	10	20,700	2,590	890	5,940
5-RD+FT	8,070	0	7,900	90	800	5,020

* R - Reference data base
FP - Flight procedure, FAA AC 91-53, maximum thrust reduction
RD - Residential development restricted to prevent encroachment after 1979 (land use)
FT - Selected flight tracks and priority runway use

a - Cost in constant 1979 dollars/1000.
b - Interpolated, 1979 - 2000

Miami

Unrestricted Encroachment Scenario. Despite the absence of land use controls, the number of people exposed to L_{dn} 65 dB and greater will decrease significantly between 1979 and 2000 because replacement of currently used older, noisy aircraft (compare 0-R data base cases). However, considerable costs will be incurred if soundproofing and relocation are provided to mitigate the adverse consequences resulting from noise exposure in excess of L_{dn} 65 dB. The use of optimized aircraft flight tracks, based on present demographics, can provide significant noise-exposure reductions.

Land Use-Control Scenario. By preventing further encroachment on airport environs by additional incompatible land uses and by optimizing aircraft flight tracks departing the airport, the number of residents exposed to greater than L_{dn} 65 dB will be significantly reduced (compare 0-R and 5, 1990 and 0-R and 5, 2000). The analysis indicates that with these measures the total cost of soundproofing residences within the L_{dn} 65- to 75-dB band and relocation of residents exposed to greater than L_{dn} 75 dB to achieve compatibility in the year 2000 will be $34 million.

LaGuardia

Unrestricted Operations Scenario. Even if neither land use controls nor operational procedures are employed to further reduce noise, the costs of soundproofing houses and relocating people will progressively decrease from the data base case of $1.4 billion in 1979 to less than $200 million by the year 2000. Optimization of aircraft flight tracks can further reduce the number of people exposed. As discussed above, use of noise-abatement flight procedures can also provide exposure reduction over the next several years. For an impact-mitigation strategy using optimized flight tracks that offers soundproofing of residences exposed to L_{dn} 65-80 dB and relocation of residents living in areas exposed to greater than L_{dn} 80 dB, the estimated minimum cost for year 2000 is $84 million.

Noise-Abatement Operations Scenario. The population model assumed for communities adjacent to LaGuardia indicated reduced population densities for the balance of the century, based on extrapolating census data for 1970 and 1977. Therefore, there was no need to be concerned with encroachment.

San Antonio

Unrestricted Encroachment Scenario. The number of people exposed to L_{dn} 65 to 75 dB will increase after 1990 because of projected population growth. By the year 2000, there will be virtually no one exposed to L_{dn} 75 dB and greater, despite the projected increase in population. The use of optimized aircraft flight tracks can reduce the number of people exposed to L_{dn} 65 dB or greater by approximately 60 percent from the 1979 data base.

Land Use-Control Scenario. A plan preventing further incompatibile land use in communities adjacent to the airport can reduce the number of residents exposed to L_{dn} 65 dB or greater by approximately 28 percent if implemented by 1990. A strategy to provide soundproofing and relocation to those remaining exposed to L_{dn} 65 dB or greater can be implemented at a total approximate cost of $48 million. That cost can be reduced to $10 million through the use of optimized aircraft flight tracks.

Sioux Falls

Unrestricted Encroachment Scenario. Despite the progressive introduction of quieter aircraft between 1979 and 2000, the number of residents exposed to noise levels of L_{dn} 65 to 75 dB and to above L_{dn} 75 dB will progressively increase because of encroachment caused by population growth. The use of optimized aircraft flight tracks can reduce the number of people exposed to noise levels of L_{dn} 75 dB and greater (1979) by approximately 70 percent from the data base; such reductions are immediate.

Land Use-Control Scenario. If implemented by 1990, prevention of further encroachment through land use controls can reduce the number of people exposed to L_{dn} 65 dB by approximately 15 percent by the year 2000. Optimizing aircraft flight tracks indicates a further reduction of 70 percent. For the conditions assumed, the results indicate that the cost to implement soundproofing of residences and relocation of residents still exposed to L_{dn} 65 dB and greater by 1990 will be approximately $5 to $6.6 million depending on whether optimized flight tracks are employed in addition to land use controls.

National Exposure Reduction

Aircraft Fleet and Number of Operations. The number of people exposed to over L_{dn} 65 dB, for the data base case, by year 2000 is reduced to one-half of the 1979 number (from 7.3 to 3.6 million, as shown by Table 5-5), because of changes in fleet composition and number of operations.

Prevention of Residential Encroachment. The 3.6 million people exposed to L_{dn} 65 dB by year 2000 can be reduced to 2.3 million by control of encroachment to the 1979 case, a 36-percent reduction.

Priority Runways and Curved Flight Tracks. A study was made of 10 airports to determine the effects of flight tracks on population exposed to over L_{dn} 65 dB. In addition to Miami, LaGuardia, San Antonio, and Sioux Falls, the airports were Chicago (ORD), New York (JFK), Los Angeles (LAX), Memphis, Indianapolis, and Dayton. Of the total population exposed at those airports, there are half as many people impacted by the noise from aircraft using the priority runways and curved flight tracks as for an equal distribution of flights from all runways and straight-in-and-out flight tracks. That result shows that the priority runway and curved flight track procedure is a valuable tool for reducing airport residential area noise exposure. Benefits from its use can be immediate.

It is recognized that the calculation of the percentage reduction in the number of people impacted by aircraft noise at a given level through use of preferential runways and curved flight tracks involved several approximations. Not having complete information on the local situation, some opportunities for improvements were missed and some assumed opportunities will not be realized. Also, it is recognized that some airports are already using preferential runways to lower the noise impact. Other airports are using runways that point toward aircraft destinations, which increases noise exposure. Thus, both the basic calculations of the aircraft-noise exposure used in this study as representing current and future operations and the present reduction in noise impact predicted to result from the use of preferential runways and curved flight tracks are approximations. The estimated noise exposure using priority runways and curved flight tracks is relative to the data base case. It is not based on assumptions as to procedures being used at a specific airport. Only by making careful studies at individual airports can the noise-exposure reduction at those airports be accurately determined.

Soundproofing vs. Relocation Costs. The costs of soundproofing residential units in the L_{dn} 65- to 75-dB band and relocation of residents within the L_{dn} 75-dB contour, as compared with soundproofing within the L_{dn} 65 to 80-dB band, and relocating residents from the area within the L_{dn} 80-dB contour were studied for the 10 airports listed above. Based on that study, the cost with relocation starting at L_{dn} 80 dB is 65 percent of the cost with relocation starting at L_{dn} 75 dB. It should be noted, however, that this shift from L_{dn} 75 dB to L_{dn} 80 dB depends on the type of housing. At LaGuardia Airport, the shift can probably go to the maximum exposure levels for the apartment-house city surrounding the airport. In areas with single-family houses on large lots, relocation should be considered. However, in those situations where an appreciable amount of land is involved, it is possible that it can be bought, cleared, and sold at a profit.

COST OF SOUNDPROOFING AND RELOCATION PER ENPLANED PASSENGER

Perhaps the most important factor in implementing a soundproofing and relocation program is the cost in relation to the airport proprietor's funding capability. This section of the report is presented as a means of illustrating the magnitude of this cost in relation to other airport operating costs.

In this analysis, the costs are determined for the following:

1. 15-year funding period,
2. the year 2000 noise exposure (FAA AC 91-39 flight procedures),
3. soundproofing residences in both the L_{dn} 65-75-dB band and the L_{dn} 65-80-dB band,
4. both equal distribution of operations on all runways and a priority runway system with curved flight tracks, and
5. both year 2000 and 1979 demographics (population and housing types and distribution around airports).

The costs pertain to the four airports presented in Table 6-1, and they are determined in relation to the number of enplaned passengers at each airport, assuming that funds are collected between 1985 to 2000.

Those calculations were made by simply dividing the program costs by the number of enplaned passengers at each airport between 1985 to 2000. No attempt was made to adjust the allocation of those costs in proportion to the noise of the aircraft, as is done in a number of foreign airports.

Soundproofing and relocation costs per passenger are given in Table 6-4. The table covers soundproofing in the L_{dn} 65 to 75-dB band for several year 2000 scenarios. The cost for LaGuardia with the soundproofing band covering L_{dn} 65-80 dB is 63¢ for the reference (R) scenario and 43¢ for the curved-flight track (CFT) scenario. The number of passengers was constant in those calculations. The cost per passenger varies with the program cost as given in Table 6-1.

Priority runways and curved flight tracks are highly beneficial at some airports. Costs per passenger for other conditions can be obtained by using soundproofing and relocation costs for the other conditions listed in Table 6-1 and dividing them by the number of passengers for the 15-year period for each airport.

TABLE 6-4. SOUNDPROOFING AND RELOCATION COSTS PER PASSENGER

	Miami	LaGuardia	San Antonio	Sioux Falls
Enplaned Passengers, 1985-2000, Millions	226.5	197.2	54.1	8.7
Costs[a]				
Scenario* (2000)				
R	0.48	.99	.82	.96
RD	0.32	.99	.38	.68
RD+FT	0.15	.55	.15	.58

a - Cost in constant 1979 dollars

*R - Reference data base
RD - Restricted development
FT - Selected flight tracks

CONCLUSIONS

Airport Categories

Category A. Improvement in reducing the number of people exposed to L_{dn} 65 dB and greater will be continuous during the balance of this century for the large hub airports. The number of people exposed to L_{dn} 65 dB and greater in the year 2000 will be less than half of the number exposed in 1979 because of changes in the air carrier fleet composition, including replacement of noisy, older-design aircraft.

Category B. The LaGuardia airport is a unique situation with respect to limitations on its operations, to location, and to surrounding demographics. The introduction of more efficient, quieter aircraft capable of transporting more passengers for approximately the same number of departures combined with a decrease in population will bring a dramatic reduction in number of people exposed to L_{dn} 65 dB and greater by the year 2000.

Category C. For the medium-size hub airports, improvements in reducing the number of people exposed to L_{dn} 65 dB and greater will be continuous until 1990. Thereafter, the number of people exposed to L_{dn} 65 to 75 dB will begin to increase. That projected increase is attributable to the combined effects of increasing operations and population, which will offset the introduction of more efficient, quieter aircraft, in the absence of any land use control or other airport operational restrictions.

Category D. Unless land use control or other airport restrictions are imposed, L_{dn} 65 dB and greater will continue to increase to the year 2000.

National Population Exposure to Airport Noise

Five conclusions can be drawn from this analysis regarding national population exposure to airport noise.

1. The number of people exposed to above L_{dn} 65 dB in the year 2000 will be approximately one-half the number exposed in 1979 because of changes in aircraft fleet composition.
2. Prevention of residential encroachment at air carrier airports between 1979 and 2000 can reduce the number of people exposed to over L_{dn} 65 dB in year 2000 by approximately 36 percent.
3. Use of priority runways and curved flight tracks to reduce the number of people exposed to aircraft noise will provide substantial and immediate benefits. The benefits are airport-site specific and highly variable.
4. Use of FAA flight procedure AC 91-53, with maximum thrust reduction, for aircraft powered by low bypass ratio engines will provide a substantial reduction in number of people exposed to above L_{dn} 65 dB.
5. Soundproofing of residences and relocation of residents exposed to above L_{dn} 65 dB provides a realistic method for achieving airport/community compatibility by year 2000. Costs per enplaned passenger range from 15¢ to 99¢ for the five conditions and four airports studied.

CHAPTER 7. GENERAL AVIATION AND JOINT CIVIL/ MILITARY AIRPORTS

NOISE EXPOSURE AROUND GENERAL AVIATION AIRPORTS

The Environmental Protection Agency (EPA) sponsored a national conference on general aviation (GA) noise and land use planning in October 1979[44] and cosponsored, with the Federal Aviation Administration (FAA), a second national conference on the same subject in December 1981.[26] A study of present and future exposure of people to noise from general aviation airports has also been conducted for the EPA.[45]

The main purpose of the Second National Conference on General Aviation Airport Noise and Land Use Planning was to continue the dialogue initiated at the First National Conference. The emphasis in that conference was the implementation of solutions at the state and local level. Another objective was to develop a document that would be useful to those dealing with GA airport-noise and land use planning.

The conference showed that while noise exposures at GA airports tend to evoke the same type of responses found at air carrier airports, the responses at GA airports occur at lower noise levels. Views expressed at the second conference indicated that the public does not want air carrier operations at a GA airport. A case was cited where the public successfully stopped installation of a parallel runway because it was perceived as an attempt to permit air carriers to enter. The conferences clearly indicated that there are noise problems associated with GA airports. Aircraft noise has in some cases posed a threat to the mere existence of some airports, such as Westchester County, New York and Santa Monica, California.

The conference produced a mixed picture regarding experience in resolving incompatible land uses around airports. Neither the airport operator nor the community have access to all the tools available to solve airport noise problems. Therefore, close interaction of those parties is absolutely required for the solution of land use compatibility problems. The primary means of accomplishing that is the establishment of committees representing aviation and community interests that are responsible for developing airport plans. States can also assist localities by the passage of supportive laws such as comprehensive planning enabling legislation identifying noise as a hazard and a consideration for planning. Supportive programs conducted by state agencies can be a means of transferring experience from one locality to another. Federal support for the planning process is currently embodied in FAR Part 150, which includes airport-noise exposure mapping and development of noise-compatibility programs and requires the program to be developed by the airport operator in consultation with the affected local government, planning agencies, and airport users. Most participants agreed that from the airport's standpoint the process had failed when litigation ensued. Experiences related by various conference participants suggested the following guidelines in addressing compatible land use problems:

1. include the community as an integral part of the planning process;
2. be honest with the community and keep promises and commitments; and
3. learn from experience, be flexible, and expect to compromise.

A study of the national noise-exposure impacts due to general aviation operations was presented by the EPA at the 1981 conference.[26] That study estimated noise exposures from 1975 to 2000 by building on an earlier study that assumed the incorporation of a 15-dB reduction in jet fleet noise levels by the year 2000.[45] In that analysis, based on overall numbers of operations rather than counts of aircraft types at each airport, an estimate of the magnitude of the area and populations exposed to L_{dn} 55, 60, and 65 dB are presented. The results of the study are shown in Table 7-1 where the areas given are the net populated areas exposed when the airport area is subtracted. Although the study shows that the total area exposed to greater than L_{dn} 65 dB is relatively small, it is significant at some airports today and will be a factor in the year 2000. Most of the community reaction is expected to occur in the areas above L_{dn} 55 and 60 dB, which are predicted to contain 1,600,000 and 500,000 people, respectively, by 2000.

TABLE 7-1. ESTIMATED EXPOSURES TO GENERAL AVIATION NOISE

L_{dn} Contours (dB)	Net Contained Area (mi.^{2}) 1975	Net Contained Area (mi.^{2}) 2000	Exposed Population 1975	Exposed Population 2000
65 and above	14	3.3	47,000	11,000
60 to 65	225	102	363,000	500,000
55 to 60	925	981	1,256,000	1,600,000

Those numbers indicate the overall dimensions of the problem. The situation at a given GA or air carrier airport with predominantly GA operations must be analayzed on the basis of its site-specific layout and its present and predicted fleet mix and numbers of operations. That is particularly true when there are significant GA jet-aircraft operations. Those airports were considered in the EPA study.[26]

Noise Exposure Around Joint-Use Airports

The EPA sponsored a study[46] of present and future noise exposure from airports in the United States that are used by both civilian and military-based aircraft. The purpose of the study was to predict how noise exposure around those joint-use airports will be affected by increasingly stringent civil-aircraft-noise regulations in the absence of similar regulation of military aircraft. The majority of joint-use airports in the study consisted of civil airports that have Air National Guard or Air Force Reserve squadrons stationed at the airfields.

The study showed that the dominant type of military aircraft at an airport has a clear influence on the effectiveness of civil-aircraft-noise regulations in reducing the area within noise contours when both civil and military operations are considered. Military aircraft types included were fighters, tankers, and transports. Since they represent 35 of 61 airports under study, joint-use airports where fighters predominate contribute the greatest amount of noise exposure as measured by land area and population. Fighter contribution was most noticeable where civil aircraft contributions were low; therefore, that aircraft type deserves the greatest attention as civil aircraft become increasingly quieter under stringent civil noise regulations. The seven airports where the KC-135 tanker was the dominant military aircraft contributed a rather constant moderate amount to the total figures. The 19 airports where the transport (C-130 and C-7) aircraft were the dominant military aircraft contribute only a small amount to the total exposure.

APPENDIX A

SUMMARY OF SOUNDPROOFING REQUIREMENTS FOR RESIDENCES ADJACENT TO COMMERCIAL AIRPORTS

(From Reference 43)

INTRODUCTION

In a recent study, the Environmental Protection Agency (EPA) investigated the costs associated with soundproofing residential structures that were located in the vicinity of airports. The effort was directed towards developing cost estimates on a national basis. However, much that was done is applicable to individual airports. This summary briefly describes that material.

In carrying out the study, several evironmental concepts were employed. Structures existing in regions where the noise exposure was less than L_{dn} 65 dB were not considered as candidates for soundproofing. Structures existing in the annular space between the two closed curves, enclosing the airport, on which the exposure levels are L_{dn} 65 dB and L_{dn} 75 dB are the ones that are being considered as soundproofing candidates. Structures in the area between the L_{dn} 75-dB contour and the airport boundary were regarded as being subjected to higher noise levels than were permissible, and their occupants were to be relocated. Relocation costs are discussed in Appendix B. Although the above criteria are the ones that were the basis of the EPA study, for completeness, soundproofing costs were also determined for structures lying between L_{dn} 75-dB and L_{dn} 80-dB contours.

In determining cost of soundproofing, it is necessary to specify not only the exterior noise that must be prevented from entering a residence, but also what noise level is to be achieved in the interior of the residence by the applied soundproofing. In the present study, an interior noise exposure of L_{dn} 45 dB is employed.

The range of exterior noise levels extended from L_{dn} 65-80 dB was considered to be too large to be properly represented by a single noise level, so it was divided into three bands. Those were L_{dn} 65-70 dB, 70-75 dB, and 75-80 dB. The centers of those bands were taken as representative of the bands. Specifically, the procedure for soundproofing a structure so that when it is exposed to an exterior L_{dn} 67.5 dB, the interior L_{dn} level is reduced to L_{dn} 45 dB is taken to represent all cases in the 65-70 dB zone. The costs associated with the procedures are also taken as costs for the band. Similarly, with the other two bands, the single L_{dn} 72.5 dB represents the 70 to 75-dB band, and L_{dn} 77.5 dB is used for the L_{dn} 75- to 80-dB band.

BASIS FOR NOISE-REDUCTION ESTIMATES

When exterior noise levels and the construction details of a room are given, classical architectural acoustics theory permits the noise level inside the room to be estimated. Specific formulas are presented that can be used for this purpose. The details of their use are described in Reference 43.

Soundproofing calculations are done on a room-by-room basis. For a given exterior level and a given room construction (walls, ceiling, windows, and doors), the resulting interior level is calculated. If it is less than or equal to L_{dn} 45 dB, the existing construction is sufficient, and no further soundproofing is necessary. However, if it exceeds that level, structural modifications (soundproofing) are required. For a room for which the construction details and the geometry are well defined, the calculations are relatively easy. However, in practice, there are a great many structures and a correspondingly large number of rooms to be considered, which make the calculations more complex. "A Study of Soundproofing Requirements for Residences Adjacent to Commercial Airports"[43] provides an orderly means for performing those calculations. That report divides single-family residences into four basic configurations and specifies the average number and type of rooms found in each. The configurations are types that are widely used and easily identifiable by observing the exterior of the structure. They are listed in Table A-1.

TABLE A-1. SINGLE-FAMILY RESIDENCE CONFIGURATIONS

House Type	Number of Rooms	Total Floor Area (Feet^2)
One Story	6	1500
Two Story	8	2000
Bi-Level	7	1750
Split Level	8	2000

The above information is extracted from Table 1 of the report,[43] which provides much additional detail regarding the number of rooms and types of roofs, floors, and doors. To minimize the number of computations, further standardization was introduced. The rooms were all considered to be the same size: 8 feet high with 250 square feet of floor space (approximately 16 feet X 16 feet). Windows were considered to occupy 12 percent of the wall area, doors to have an area of 20 square feet, and sliding glass doors to have an area of 40 square feet.

The noise level that is found in the interior of a room depends on the amount of acoustical absorption in the room as well as on other factors. Data obtained by Wyle in previous studies shows that the number of absorption units (Sabins) in a given room is roughly independent of frequency. For rooms with 250 square feet of floor area, the data shows that the number of absorption units (A) is about 300 Sabins and that 10 Log_{10} (A) is 25. This value of 25 was used throughout.

The considerations and standardizations above apply to single-family houses. Similarly, related assumptions were also made for multi-family dewllings.

RESIDENTIAL CONSTRUCTION CHARACTERISTICS

This section is concerned mostly with the materials from which the walls, roofs, floors, and windows are made. They are important because they control the fraction of sound energy impinging on the exterior surfaces of a structure, which is transmitted to the interior. Heavy elements transmit only a small fraction of the incident sound energy. Light or leaky elements (those having an air path through them) permit a large portion of the incident sound energy to penetrate to the interior.

The contractor considered many kinds of practical housing constructions and tabulated the frequency of use of each kind. By the process of eliminating the uncommon construction types and combining some of the common types, a set of basic categories was developed that permitted the approximate description of most types of construction.

Much of the preceding information was fed into a computer, and the noise reductions achieved by various constructions were examined. Several general conclusions were drawn.

1. Depending only on the types of windows and door, noise inside dwellings is 18 to 27 dB less than it is outside.
2. The difference between poor and good conditions is approximately 2 dB. Extremely poor weatherstripping can result in even larger differences.
3. Adding storm windows can decrease noise levels by about 4 dB.
4. The noise levels of rooms with doors is 4 to 6 dB less than those of rooms without doors.

FIELD SURVEY

Since one of the purposes of the EPA study was to estimate the national cost of soundproofing residences near airports, a survey was conducted to determine how many of each kind of single-family and multi-family dwellings actually existed. Ten airports were selected, and a team of experienced observers drove through appropriately chosen areas and counted the number of structures of each type. The survey procedure and the results are fully presented in Reference 43. They are not discussed further here because the survey data for a single airport study should be much more detailed. It is necessary to obtain sufficient information so that a reasonably good computation of soundproofing can be made for each residence. The cost estimate must be reasonably close to the actual cost so that the program can be properly funded. In particular, the people conducting the survey must be permitted to observe and measure in the interior of each dwelling. A comprehensive survey technique must be developed.

SOUNDPROOFING MODIFICATIONS AND COSTS

The actual detailed calculations showing how much noise reduction is associated with a given room configuration are done by employing a basic equation.[43] The transmission coefficients for the various types of structural elements are obtained. The areas are standardized and have been discussed earlier. The quantity 10 Log_{10} (absorption units) is taken as 25. The equation is programmed on a computer, and runs are made showing the noise reduction achieved by the original construction and by any given modification. Computer calculations of this type are used to determine the benefit of any particular modification. Approximations of the required improvement in noise reductions for various cases are calculated and tabulated. A typical example showing how the tabular values are obtained is the case of a hollow-core-door structure with seals in good condition. Assume that the structure is located in the L_{dn} 65- to 70-dB zone. That zone has a mean of L_{dn} 67.5 dB. The desired interior level is L_{dn} 45 dB. The necessary noise reduction is 67.5-45.0 = 22.5 dB. According to Table 2 in the report,[43] a hollow-core structure, with no storm windows, and good seals has a noise reduction (referred to as baseline, noise reduction) of 19 dB. But 22.5 dB is needed; hence, the noise reduction of the original structure must be increased by 3.5 dB.

Once the required increase in noise reduction has been established, there are three basic techniques of achieving that reduction, which should be employed sequentially.

1. Seal all leaks in the exterior structure, which can reduce noise levels by approximately 2 dB.
2. Install storm windows and storm doors and increase the mass of existing doors or replace them with heavier doors, which can provide a reduction of up to 10 dB.
3. Increase the mass of exterior walls and roofs or replace them with heavier ones, which is an expensive, although effective procedure, that should only be used as a last resort.

Those procedures are discussed in the report, which also gives a very brief discussion of ventilation requirements and their relation to the soundproofing problem.

The details for calculating the cost of an individual soundproofing case are standard and are not elaborated on in the report. They comprise materials, labor, overhead, and profit. In addition, there are a few miscellaneous terms, which constitute an additional markup of 30 percent. They are as follows:

1. cost of architectural drawings, permits, etc.;
2. miscellaneous costs for sealing leaks, for modifying kitchen vents, chimneys, etc., and for making minor repairs to existing structures; and
3. contractor's contingency.

Ordinarily, there are several alternate designs that will produce a desired additional noise reduction. In the present report, the contractor has programmed a computer so that selections of several different designs, having approximately the same noise-reduction capabilities, are automatically made, and the cost associated with each is calculated. The computer prints out the cost of the least expensive design. Those costs (in 1981 dollars) are shown in Tables 8, 9, and 10 of the EPA report.[43] The tables cover structures of sizes from one unit (single-family dwellings) up to 50 units. They also apply to structures in the noise bands L_{dn} 65-70 dB, L_{dn} 70-75 dB, and L_{dn} 75-80 dB. In addition, the costs are categorized by region. (Refer to Figure A-1.) The additional cost for air conditioning is also provided for each region. This information has been extracted from the report and is reproduced here as Figure A-1 and Tables A-2, A-3, and A-4.

When soundproofing is added to a structure, it not only increases the acoustic transmission loss, but it also increases the thermal insulation, which, in turn, results in decreased fuel costs. Based on assumptions that are stated in the report, the following savings can be realized from soundproofing in the corresponding L_{dn} zones:

Location of Dwelling L_{dn} Zone	National Average Annual Fuel Savings (1981 Dollars)
65-70 dB	$ 40
70-75 dB	$130
75-80 dB	$290

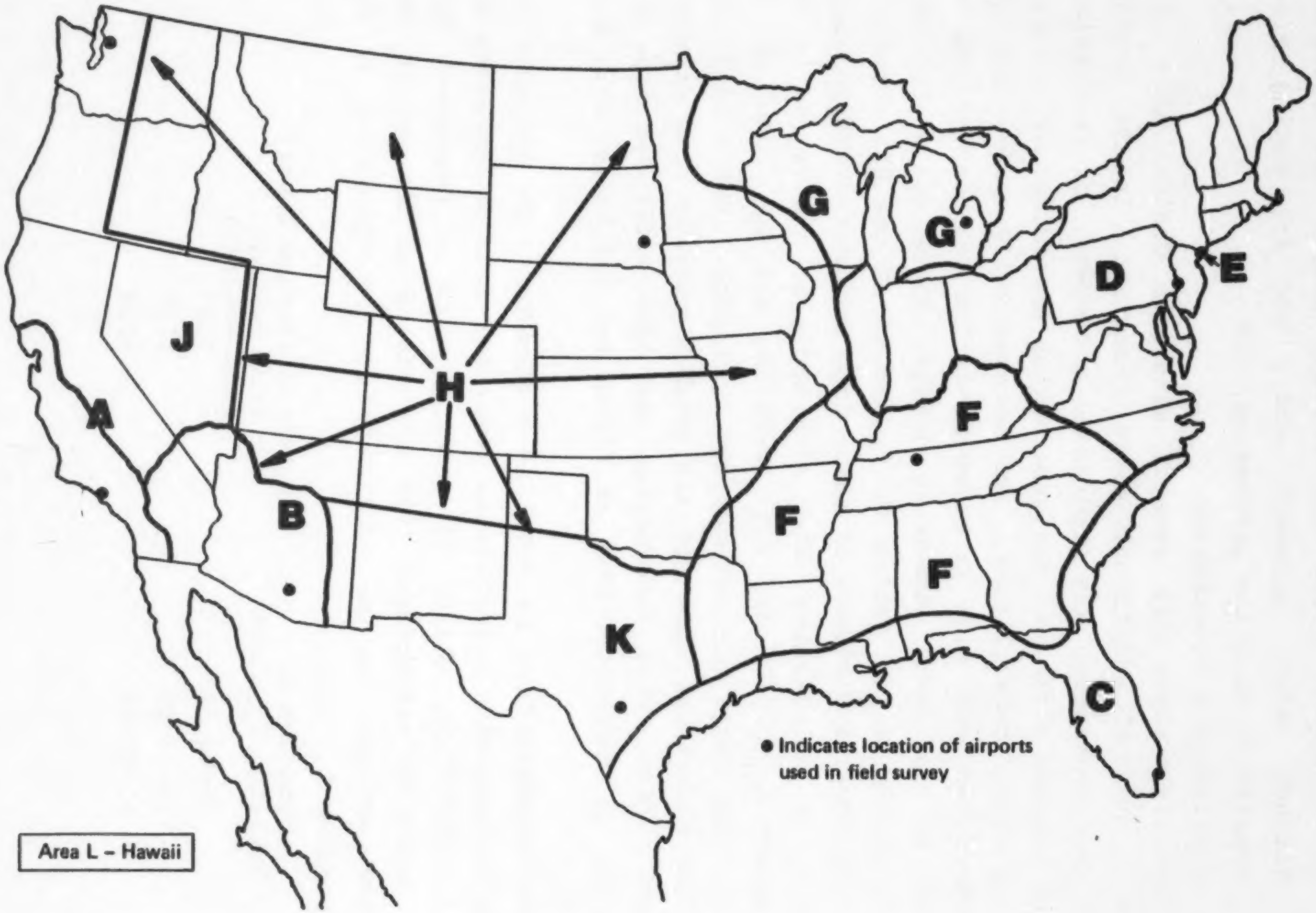
A
B
C
D
E
F
F
F
G
G
H
J
K
• Indicates location of airports used in field survey
Area L - Hawaii

FIGURE A-1. REGIONS OF DIFFERING CONSTRUCTION PRACTICES

TABLE A-2. AVERAGE COST (IN 1981 DOLLARS) PER DWELLING TO SOUNDPROOF SINGLE-FAMILY DWELLINGS

L_{dn} Zone	Region										
	A	B	C	D	E	F	G	H	J	K	L
65-70 dB	2,600	1,400	2,300	2,500	4,800	1,800	2,500	1,100	2,700	2,100	3,800
70-75 dB	5,800	3,100	5,400	7,400	9,500	3,800	8,500	5,000	7,700	6,000	10,400
75-80 dB	12,800	8,200	11,000	15,100	18,000	10,000	16,100	13,600	14,900	11,700	18,200
Additional Cost For Air Conditioning	1,500	800	400	1,000	1,600	400	1,300	1,700	2,500	700	2,600

TABLE A-3. AVERAGE COST (IN 1981 DOLLARS) PER DWELLING TO SOUNDPROOF MULTIPLE-FAMILY DWELLINGS

TWO DWELLING UNITS

L_{dn} Zone	Region										
	A	B	C	D	E	F	G	H	J	K	L
65-70 dB	800	900	800	700	700	800	800	700	800	800	800
70-75 dB	2,900	1,900	2,000	1,200	1,200	3,400	3,400	1,200	2,600	2,600	2,500
75-80 dB	7,000	5,000	5,100	3,000	3,000	6,500	6,500	3,000	5,600	5,700	5,200

THREE TO FOUR DWELLINGS UNITS

L_{dn} Zone	Region										
	A	B	C	D	E	F	G	H	J	K	L
65-70 dB	800	900	800	700	700	700	700	700	800	800	800
70-75 dB	2,200	1,700	1,700	1,000	1,000	2,700	2,700	1,000	2,200	2,200	2,200
75-80 dB	5,300	4,200	4,200	2,500	2,500	5,100	5,100	2,300	4,500	4,800	4,800

Average cost for additional air conditioning is $400 per unit.

TABLE A-4. AVERAGE COSTS (IN 1981 DOLLARS) FOR SOUNDPROOFING MULTI-FAMILY DWELLINGS

FOR ALL REGIONS

L_{dn} Zone	Number of Units		
	5-9	10-49	50
65-70	700	700	700
70-75	900	800	800
75-80	1,600	1,200	1,000

Average cost for additional air conditioning is $400 per unit.

CONCLUSIONS

It is believed that the subject report will be useful to airport managers and others who may be planning soundproofing projects, first, because it organizes the procedure and shows how many of the necessary calculations can be performed and, second, because it provides technical and cost data that can be used for comparison and preliminary estimates.

APPENDIX B

SUMMARY OF AIRPORT COMMUNITY RELOCATION COSTS

(From References 42 and 47)

INTRODUCTION

Recently the Environmental Protection Agency (EPA) conducted a study that dealt with the alleviation of the noise problem that exists in the vicinity of air carrier airports. Although the study was for the purpose of developing a national assessment, much was produced that is of interest to persons concerned with noise problems at individual airports.

It is the purpose of the present section of this report to summarize the information acquired in the EPA study and also suggest methods for obtaining certain necessary data that is "site specific" for each airport.

The basis used in the EPA study referred to above was the Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970.[48] This will be called hereafter the Act.

It is recognized that in most cases it is not manadatory that the provisions of the Act be adhered to. However, the Act does identify the types of costs encountered in the relocation process and also proposes methods of determining these costs. It is felt that such information is useful to any planner of a potential relocation and so it is discussed in this report. The numerical values of the costs presented in the Act may not be applicable but the type of costs probably will be valid at the time a planner undertakes his study. He can at that time use cost data appropriate to the situation.

To calculate the total cost of relocation, it is necessary to have not only the cost of each case but also the number of each type of case. In the EPA report, the number of cases was estimated by the use of two computer programs. The first is called Integrated Noise Model (INM). It established a closed curve (contour) surrounding an airport. Inside that contour, the noise exposure was considered sufficiently high so that all residents who were situated in the area between the contour and the airport boundary would be relocated. In the EPA study, the contour was a curve such that at all interior points the noise exposure was L_{dn} 75 dB or greater. It would appear that any future study would require the establishment of a similar contour to define the area in which the relocation is to take place. In this connection, it may be helpful to note that the Federal Aviation Administration (FAA) will provide the INM computer program for a nominal fee to anyone who has a need for it.

The second computer program employed was one that provided demographic information based on 1970 census data. This program was called "SITE II"; it was prepared by the CACI Corp. An updated version, employing 1980 census data, will be put on the market by CACI in the near future. For its work EPA had access to a computer program called ALAMO, which was owned by the National Space and Aeronautics Administration (NASA). ALAMO comprised INM and SITE II in tandem and its output provided demographics for the region inside the contour directly.

The SITE II, appropriately updated, was satisfactory for the purpose of making a national estimate, but it is not suitable for determining with sufficient precision the demographic parameters which are necessary for the costing of a relocation program. These must be established by surveys and appraisals taken in the region of interest. Later in this report, the needed demographic quantities will be specified.

CLASSIFICATION OF CASES ACCORDING TO THE ACT

General

A study of the Act reveals that it defines four situations for which financial reimbursement is available to relocatees. Those could well be applicable to individual airport relocation studies. They are:

1. renters who become homeowners,
2. renters who remain renters,
3. rental property to be purchased, and
4. owner-occupied units to be purchased.

Each of those cases is entitled to financial reimbursement and those constitute costs to an organization that is funding the relocation program. The cost elements are shown in Table B-1 and are discussed briefly in the following text.

TABLE B-1. COST ELEMENTS AND RELOCATION CASES

Cost Element	Relocation Case* A	B	C	D
Advisory Service Cost	X	X	X	X
Moving Cost	X	X		X
Purchase Price			X	X
Replacement Cost	X			X
Increased Interest Cost				X
Closing Cost				X
Downpayment	X			
Foregone Earnings			X	

*Relocation Cases

A. Renters who remain renters
B. Renters who become homeowners
C. Rental property to be purchased
D. Owner-occupied units to be purchased

Renters Who Remain Renters

The first case is composed of existing renters who elect to remain renters. Section 204 of the Act provides for payments to tenants in displaced dwellings who were tenants for at least 90 days before the initiation of negotiations for acquisition of such dwellings. Those persons are entitled to a rent supplement for up to four years in the event that the rent in a replacement unit exceeds the rent the displaced person is paying at the time of relocation. Such payments may not exceed $4,000. Renters are also entitled to the advisory services of the local relocation agency (Section 205) and to reimbursement for moving expenses.

Renters Who Become Homeowners

The Relocation Act recognizes that renters who are dislocated may want to purchase their own homes as an option to moving to another rental property. These people are entitled to the advisory services of the relocation agency and reimbursement for moving expenses. In addition, there is a special provision in Section 205 of the Relocation Act making money available for downpayments (including incidental expenses) on replacement homes. Such payments shall not exceed $4,700, except that the renter must match any amount paid in excess of $2,000.

Rental Property To Be Purchased

The third relocation case is made up of rental property to be purchased. Owners of those properties are entitled to the fair market value of their rental units. Because landlords typically suffer a disruption of their business operations and lose their existing tenants in the course of the relocation, they may elect to accept a compensatory payment to cover the cost of their foregone earnings from the rental units. Such payments are distinct from payments to dislocated renters addressed under the prior two cases.

It is interesting to note that other businesses may also be disrupted by the relocation of their existing patronage (e.g., neighborhood grocery stores). The owners of those businesses are also entitled to a compensatory payment.

Owner-Occupied Units To Be Purchased

The fourth and most complex relocation case is made up of owner-occupied units to be purchased. Relocation homeowners are entitled to the services of the relocation agency and reimbursement for moving costs. The homeowners are also entitled to the purchase price (at fair market value) of their homes, a supplemental payment over and above the fair market value in the event that the purchase price of the comparable replacement home exceeds the fair market value of their homes in the area exposed to excessive airport noise. They are also entitled to compensation for any increased interest costs resulting from liquidating the original mortgage and taking out a new mortgage on the replacement dwelling at the current mortgage interest rate, and any closing costs involved in the purchase of the replacement home.

ELEMENT COSTS

General

Estimates are provided here of the dollar amount of each cost element identified in Table B-1. The costs are estimated for the base year 1979. Information provided by the Federal Highway Administration (FHWA) is used to measure advisory service costs, moving costs, and closing costs in 1979. Figures provided by FHWA are rounded off to the nearest one hundred dollars.

Other cost elements are estimated by applying updating procedures to the 1970 Demographic Profile Report. The emphasis is on the procedures used to estimate the cost elements rather than the numbers presented. Each cost element listed in Table B-1 is discussed below.

Advisory Service Costs

Advisory service costs are costs incurred by the relocation agency. They cover such activities as appraisal, negotiations, relocation assistance, and administration. They may also include the cost of locating and appraising three or more comparable replacement housing units for each unit to be vacated. This activity is recommended by the Relocation Act and is used to determine the reasonable cost of replacement housing and to provide the dislocated households with alternatives. The households may reject the alternatives and find their own replacement housing, but they will be subject to the reasonable cost estimates of the relocation agency.

In 1979, the service costs of relocation incurred by the FHWA averaged $1,200 per case.

Moving Costs

Moving costs are incurred by all relocated households. Under the Relocation Act, households may be compensated for actual costs or may elect to receive a fixed allowance. Under the Act, all moves are local or treated as if they were local.* In 1979, 84 percent of all households relocated by the Department of Transportation (DOT) chose to receive the moving allowance plus dislocation allowance totaling $500 per household or less. The remainder were compensated for actual costs, which averaged $1,200 a household. The average moving cost per household paid by DOT in 1979 was approximately $500.

Purchase Price of Rental Property

Under the Relocation Act, all owners who must vacate their dwellings are entitled to receive fair market value for their residential rental property.

The practical method to determine the proper amount of reimbursement is simply to have the property appraised. This should be done for all situations in which real costs, which must be funded, are required.

In the case of EPA's study, this procedure was not feasible, and an estimation method based upon monthly rental was employed. This is outlined below.

---

*The Act covers only "reasonable expenses," and most agencies interpret this as a move not exceeding 50 miles. A person moving more than 50 miles would have to absorb the extra costs associated with a long distance move.

The formula used is:

$$C = \frac{12\ R\ U}{i}$$

Where: C = The fair market value of a typical rental property in a given year.

R = The monthly rental income from a typical rental unit in that same year.

U = The average number of units per rental property.

i = The estimated mortgage interest rate in that year.

That equation is a simplification of a complex relationship in that it ignores capital gains, depreciation, maintenance costs, taxes, and anticipated changes in rents and interest rates. It is assumed that those complicating factors tend to offset one another so that the equation provides an adequate estimate of the present value of rental property.

Purchase Price of Owner-Occupied Units

As in the case of rental property, the purchase price of owner-occupied units is established by appraisal. In the EPA study that cost was determined from 1970 census data, which was updated by a mathematical procedure. That is not given here since it would not be useful in an actual costing situation.

Replacement Cost

Relocated tenants and homeowners receive a payment to cover the increased rental or purchase price required to obtain comparable replacement housing in a quieter neighborhood. For the EPA study, it was necessary to estimate that replacement cost and a theoretical rule that stated that property values decline at the rate of one-half-of-one percent per decibel increase in noise level was employed. In a practical airport situation, this calculation should be done by utilizing the services of real estate brokers and multiple listing service tables. Each airport must be considered individually. However, the process is quite straightforward and will pose no problems for the estimator.

Increased Interest Cost

The increased interest cost occurs when the interest rate on the replacement mortgage exceeds the interest rate on the original mortgage. To ensure that the relocation does not impose a financial burden on the relocated homeowner, special compensation is made to offset the increase in interest rates. No compensation is required if there is no increase in interest rates or if the acquired property is not encumbered by a bona fide mortgage.

For convenience the section of the "Act" that deals with this question is given below.

> "(B) The amount, if any, will compensate such displaced person for any increased interest costs which such a person is required to pay for financing the acquisition of any such comparable replacement dwelling. Such amount shall be paid only if the dwelling acquired by the Federal agency was encumbered by a bona fide mortgage which was a valid lien on such dwelling for not less than one hundred and eighty days prior to the initiation of negotiations for the acquisition of such dwelling. Such amount shall be equal to the excess in the aggregate interest and other debt service costs of that amount of the principal of the mortgage on the replacement dwelling which is equal to the unpaid balance of the mortgage on the acquired dwelling, over the remainder term of the mortgage on the acquired dwelling, reduced to discounted present value. The discount rate shall be the prevailing interest rate paid on savings deposits by commercial banks in the general area in which the replacement dwelling is located."

The concepts implied in the Act are best explained by the example given below.

Suppose that a relocatee had purchased his home 10 years before the time of relocation. At that time, he took a mortgage of $50,000 with a term of 25 years at an interest rate of 9 percent per year. His monthly payment would be $419.60. At the time of relocation, the unpaid balance on his mortgage would be $41,369.62. When the relocatee purchases a new home, he is compensated for any additional interest costs incurred by his having to borrow $41,369.62 at a higher rate of interest for 15 years (the time his first mortgage had to run). If we assume that the interest rate at the time of relocation is 16 percent per year, then the relocatee would have to pay $607.60 per month to liquidate his debt in 15 years. This is $607.60 - $419.60 = $188.00 per month more than he had been paying before relocation. The present value of this annuity at the prevailing interest rate paid on savings deposits by commercial banks in the general area in which the replacement dwelling is located, for a period of 15 years, is the compensation paid the relocatee for increased interest cost. In the present case, we will assume a bank interest rate of 5.5 percent per year. This gives $23,008.66 as the amount the relocatee would receive.

Of course, in the case of any particular airport, the above procedure could be modified to fit the need of the involved community.

Closing Costs

Closing costs are incurred by all persons making a home purchase. The EPA report utilized the experience of DOT in estimating these costs. In 1979, the Department of Transportation reports that closing costs associated with relocation averaged $400 per unit. Closing costs are low because the relocation agency provides guarantees to lending institutions and acts, to some extent, as legal representative for the relocated households. Also, all households participating in the relocation program are typically exempt from all taxes associated with the sale of their original units and the purchase of the replacement units.

In the case of an interested airport, the costs can be determined by consultation with real estate and legal personnel.

Downpayment

The Federal Relocation Act has a special provision designed to assist tenants in becoming homeowners. Specifically, $2,000 is available outright to tenants for use as a downpayment and an additional $2,000 is available on a matching basis. We assume that each tenant electing this option has at least $2,000 to put toward a downpayment and, therefore, is eligible for the full $4,000 downpayment allowance.

Airports involved in relocation activities could provide downpayments patterned after those in the Act. However, it should be kept in mind that the cost numbers in the Act were established in 1970. Revised numbers would probably be necessary in any future relocation.

Income Foregone

In the course of relocation, owners of rental property typically suffer losses. Those occur because of many things including loss to tenants. These are regarded as business losses, and the owners are compensated up to the average amount of their net annual earnings on the property provided that amount is equal to or greater than $2,500 and is less than or equal to $10,000.

The conditions associated with the income foregone are quite detailed, and anyone desiring to discover how the Act deals with this question should study the Act.

It is quite likely that rules for calculating income foregone should be drawn up by the airport group interested in relocation. Those could be tailored to meet the needs of the community and perhaps be better than the rules given in the Act.

TOTAL COST

General

In the preceding section, the various individual costs associated with the relocation process were discussed. Those are listed in Table B-1. Average values for each cost element that are appropriate for the area should be established. This is best done by careful study of the situation in the neighborhood of interest. That means that the cost of advising servicing, moving costs, etc. should be determined by studies made at the place and time of interest. The costs are essentially those associated with property transfer, and the aid of real estate brokers should be sought.

Number of Relocation Cases

To determine total cost of relocation, it is necessary to know not only average individual costs, but also the number of cases in which these individual costs are involved. Table B-1 divides the relocatees into four groups, calling each a relocation case. These are:

Relocation Case	Description of Case
A	Renters who remain renters
B	Renters who become homeowners
C	Rental property to be purchased
D	Owner-occupied units to be purchased

In the EPA report, it was necessary to estimate the number of each of the cases A, B, C and D by indirect means. That process yielded only rough approximations to the actual number of cases of each type. This is not adequate for determining how much money is necessary to fund an actual relocation project. In that situation it is necessary to know precisely what the financial requirements are. One way to ascertain the number of cases is to require affected persons to fill out a questionnaire in which they disclose their intentions. That could be done by mail. Another way is to hire a poll-taking organization to make a survey. The survey could cover 100 percent of the population in the case of a small airport, or a statistically significant sample in the case of a large airport. In any case, a direct head count (or adequate sample) is the best means for determining the number of A's, B's, C's and D's.

The total cost is obtained, of course, by summing the products of the number of each case by the cost per case.

Summary

Most of the material presented in this report has been extracted from the report on "Relocation Costs." It comprises the information, originally developed for national relocation cost assessment, which is deemed useful to an airport manager who is concerned with relocation in his own area. The major items covered are:

1. a method for classifying relocatees that is helpful in carrying out the costing process,
2. identification of the various cost elements and suggestions as to how the associated cost dollars could be determined, and
3. notes on how the total cost of the relocation process can be determined.

REFERENCES

1. Report on Aircraft-Airport Noise, U.S. Environmental Protection Agency, August 1973, Washington, D.C.
2. Toward a National Strategy for Noise Control, U.S. Environmental Protection Agency, April 1977
3. Aviation Noise Abatement Policy, U.S. Department of Transportation, November 18, 1976
4. Environmental Criteria and Standards, Department of Housing and Urban Development, Federal Register, Thursday, July 12, 1979
5. Airport Noise Litigation - Case Law Review (1973-1980), Bennett, R. L., EPA, 550/9-82-326, NTIS No. PB82-162-066
6. Griggs v. Allegheny County, 369US84 (1962)
7. Greater Westchester Homeowners Association vs. City of Los Angeles, 26 Cal. 3d 86, 160 Cal. Rptr. 733, (Cal. Sup. Ct. 1979)
8. Federal Aviation Regulations Part 36, Noise Standards: Aircraft Type and Airworthiness Certifications, Published 18 November 1969 (34FR18355)
9. Federal Aviation Regulations Part 36, Noise Standards: Aircraft Type and Airworthiness Certification, Amendment 36-2, Noise Standards for Newly Produced Airplanes of Older Type Designs, Published 20 October 1973 (38FR29569)
10. Federal Aviation Regulations Part 91, General Operating and Flight Rules, Amendment 91-136, Phased Compliance with Part 36 Noise Limits by Turbojets with Maximum Weights Greater than 75,000 Pounds, Published 23 December 1976 (41FR56016)
11. Noise Levels for Turbojet Powered Airplanes and Large Propeller Driven Airplanes, EPA, NPRM 76-22 (41FR4738), October 1976
12. Federal Aviation Regulations Part 36, Noise Standards: Aircraft Type and Airworthiness Certification, Amendment 36-8, Noise Limits and Acoustical Change Requirements for Subsonic Transport Category Large Airplanes and Turbojet Powered Airplanes, Published 2 March 1978 (43FR8722)

13. Federal Aviation Regulations Part 36, Noise Standards: Aircraft Type and Airworthiness Certification, Amendment 36-4, Noise Standards for Propeller Driven Small Airplanes and Acoustical Change Provisions, Published 6 January 1975 (40FR1024 and 40FR6346)
14. FAR Part 36 Compliance Regulation, Final Environment Impact Statement, FAA, November 10, 1976
15. Federal Aviation Regulations Part 91, General Operating and Flight Rules, Amendment 91-112, Civil Aircraft Sonic Boom, Published 28 March 1973 (38FR8051)
16. Federal Aviation Regulations Part 91, General Operating and Flight Rules, Amendment 91-134, Minimum Certificated Landing Flap Setting, Published 29 November 1976 (41FR521388)
17. Recommended Noise Abatement Takeoff and Departure Procedure for Civil Turbojet Powered Airplanes, FAA Advisory Circular A/C 91-39, 18 January 1974
18. Noise Abatement Departure Profile, FAA Advisory Circular A/C 91-53, 17 October 1978
19. Airport and Airway Development Act, Amendments of 1976, Public Law 94-353, H.R. 9771, July 12, 1976
20. Federal Aviation Regulations Part 150, Noise Standards: Airport Noise Compatibility Planning, Establishment of New Part 150 to Govern the Development and Submission of Airport Operator's Noise Compatibility Planning Programs and the FAA's Administrative Process for Evaluating and Determining the Effects of those Programs. Published 26 January 1981 (46FR8316)
21. Aviation Safety and Noise Abatement Act of 1979, Public Law 96-193, February 18, 1980
22. Airport Noise Regulatory Process, EPA, October 1976 (41FR51522)
23. Airport Noise Compatibility Planning and Programs, FAA, Under P.L. 91-258 and P.L. 96-193, October 1981
24. Airport-Land Use Compatibility Planning, FAA, Advisory Circular A/C 150/5050-6, December 30, 1977

25. Actions Affecting Land Use Compatibility at U.S. Airports, EPA, Report No. 550/9-82-340, March 1982, NTIS No. PB82-240-375

26. Second National Conference on General Aviation Noise and Land Use Planning, EPA, Report No. 550/9-82-337, April 1982, NTIS No. PB82-218-520

27. Airport Community Soundproofing and Relocation Study, EPA, No. 550/9-82-343, June 1982, NTIS No. PB82-

28. INM Integrated Noise Model, Version 2 User's Guide, Connor, T., FAA Report FAA-EE 7909, September 1970

29. An Airport Community Noise Impact Assessment Model, DeLoach R., NASA TM-80198, July 1980

30. U.S. DOT, FAA, Airport Activity Statistics of Certificated Route Air Carriers, Calendar Year 1979 (AA), FAA/CAB Report, December 1979

31. User's Manual for Automated Calculation of Fleet Noise Level and Airport Noise Index, Benson, W., EPA, No. 550/9-82-342, September 1981, NTIS No. PB82-

32. Airport Information File for Analysis and Modeling, Winer, D.E. and C. Wine, paper presented at the International Conference on Air Quality and Aviation, October 16-18, 1978

33. U.S. DOC, Airport/Facility Directory, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Washington, D.C., September/November 1978

34. AOPA's Airports U.S.A. 1979, published by the Aircraft Owners and Pilots Association, Washington, D.C., 1979

35. INM, Integrated Noise Model, Version 2 - User's Guide, Connor, T., R. Hinckly, et al, FAA Report FAA-EE-79-09, September 1979

36. Clustering Algorithms, Hartigan, John A., Wiley Laboratories, 1975

37. FAA, Aviation Forecasts, Fiscal Years 1981-1992, Table 3, September, 1980

38. User's Manual for the ALAMO Demographic Report Generator Program (DEMCOM), EPA, Report No. 550/9-82-341, September 1981, NTIS No. PB82-240-367

39. Noise Exposure of Civil Air Carrier Airplanes Through the Year 2000, Volume I: Methods, Procedures, Results, Bartel, C. and L. Sutherland, EPA, Report No. 550/9-79-331-1, February 1979
40. FAA, Air Traffic Control Handbook 7110, 65B, Section 4, Runway Use
41. Department of Commerce, Climatography of the United States, No. 90 (1965-1974), National Climatic Center, Ashville, N.C.
42. Procedures to Estimate Residential Relocation Costs, Chais, Richard, et al, EPA, Report No. 550/9-82-327, April 1981, NTIS No. PB82-239-641
43. A Study of Soundproofing Requirements for Residences Adjacent to Commercial Airports, EPA, Report No. 550/9-82-328, August 1981, NTIS No. PB82-250-168
44. Conference on General Aviation Airport Noise and Land Use Planning, Volumes I, II, and III, EPA, Report No. 550/9-80-320A, B, C, February 1980, NTIS No. PB82-218-090, -105, -116
45. Community Noise Around General Aviation Airports From Year 1975 to 2000, Wm. J. Galloway, et al, EPA, Report No. 550/9-82-339, January 1981, NTIS No. PB82-239-666
46. Noise Exposure Around Joint Use Airports, Dwight Bishop, EPA, Report No. 550/9-82-338, April 21, 1982, NTIS No. PB82-
47. Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970, 42 USC 4601, 1971